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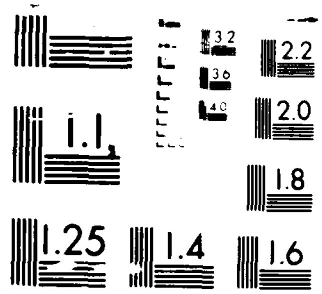

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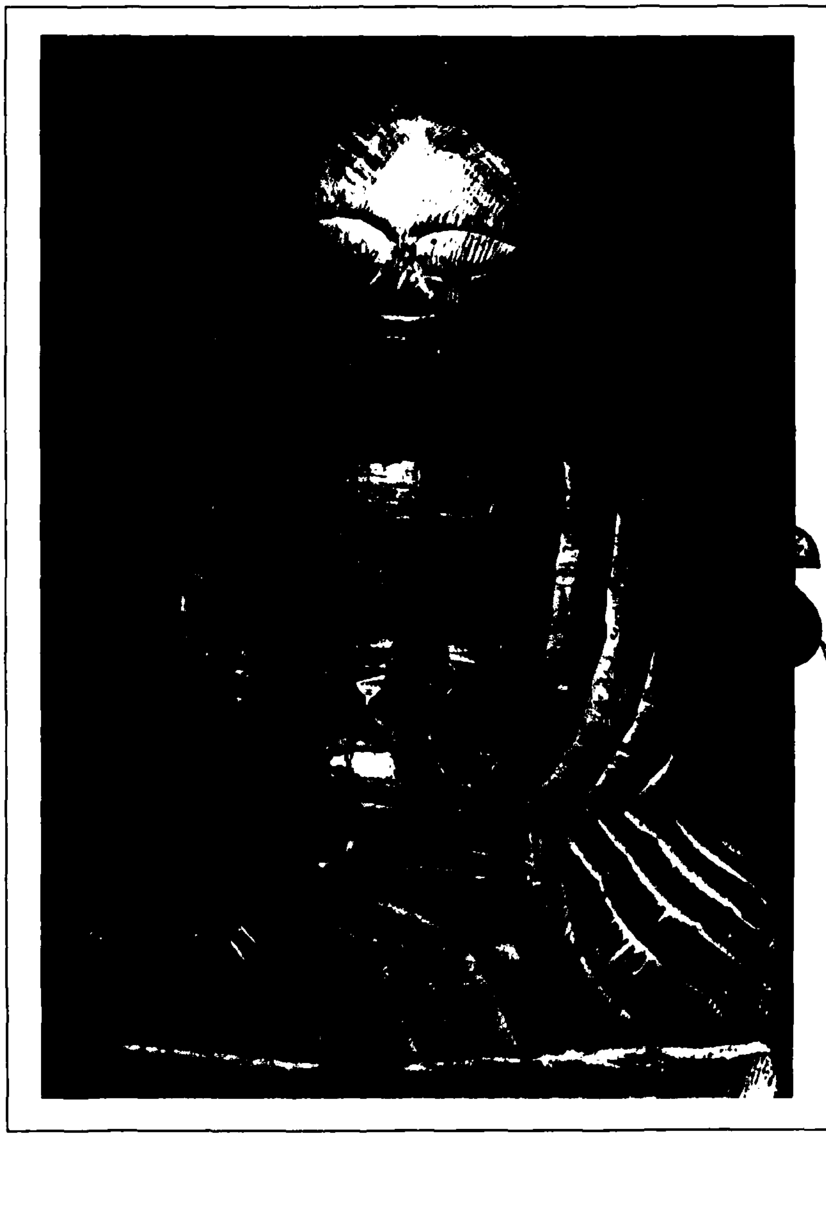

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This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONR Far East and the Air Force Office of Scientific Research with certain reports also being contributed by visiting state-side scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work, considered to be of special interest.

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18. Subject Terms (Key Words) continued

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Semiconductor lasers
Semiconductor materials
Double heterojunctions
Superlattices
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Distributed feedback lasers
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Ceramics
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Fracture behavior
Composites
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Controlled nuclear fusion
Axisymmetrical accelerator
Self-crowbarring electromagnetic accelerator
Hovercraft
Optical cavities
Engineering energy bandgaps
Quantum wells
Visible lasers
Integrated lasers
High power lasers

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CONTENTS

Cover: This wood–carved bishobutsu (Buddha with a smile) was created by Enku, who was born in 1632 in Gifu prefecture. Enku renounced the world at the age of 23 and began to carve the Buddhist images at about the age of 32. He vowed to carve 120,000 Buddhist images. He traveled around the country with a hatchet, chisel, and small knife to carve the natural logs for more than 30 years until he passed away at the age of 64. The roughly cut texture of the Buddhist images is simple and shows strength. Enku kept the natural shape of the logs and integrated the natural grains in his designs. This photo was reproduced from a postcard by Takao Kotake of Take Productions.

THE OPTOELECTRONICS JOINT RESEARCH LABORATORY: LIGHT SHED ON COOPERATIVE RESEARCH IN JAPAN

James L. Merz

INTRODUCTION

In 1985, a very significant event occurred in the semiconductor industry. The country of Japan sold about $10 billion worth of semiconductor devices and integrated circuits, equaling or surpassing the United States' share of the world's market for the first time. Although it is difficult to make an exact comparison between the two countries (Ref 1), sales statistics for a few preceding years suggested that this would eventually happen. The process was accelerated in 1985 because of two factors: (1) the slump during most of 1985 in the semiconductor industry, which appears to have affected the United States more than Japan; and (2) the depreciation of the dollar relative to the yen that occurred dramatically in the fall of 1985 so that constant Japanese sales in yen produced an apparent increase in sales in dollars. Nevertheless, the fact that Japan has finally caught up to the United States in the semiconductor market will have profound effects on the industry in this country, and many people are asking how this happened. Much has been published about the growing strength of the Japanese semiconductor industry; a few examples are given in References 2 through 5. One of the major reasons often given for this dramatic increase in semiconductor technology in Japan has been the establishment of cooperative research projects between industry and the Japanese government through the Ministry for International Trade and Industry (MITI). In particular, the establishment of joint laboratories with personnel shared from member companies has been an innovative approach to research and development in Japan. During the fall of 1985, I had the great fortune to be invited to serve as a visiting researcher in one of those cooperative laboratories, the Optoelectronics Joint Research Laboratory, and in this paper I would like to share some of my observations from that experience.

Optoelectronic devices and the III-V compound materials from which they are fashioned represent only a small portion of the semiconductor industry. Japanese sales for both III-V semiconductors and silicon are compared in Table 1. Two interesting facts are seen in this table:

1. For both III-V compounds and silicon, the substrate sales represent about 10 percent of the device and circuit sales.

2. For both substrates and devices, III-V compounds represent about 5 percent of the total market.

Thus, although not a major contributor to semiconductor economics, III-V compound sales are not insignificant. I think, therefore, that my experiences at the Optoelectronics Joint Research Laboratory provided meaningful information about what is happening in the semiconductor industry in Japan. It should be noted that by U.S. estimates, the Japanese have captured at least 80 percent of the total noncaptive market of III-V compound substrates and devices. To put these numbers in proper perspective, it should be noted that the Japanese are building a complete optoelectronics industry at the system level. This industry

did not exist in 1980, accounted for $4.8 **billion** in sales in 1985, and is projected by the Japanese to amount to **$60 to $70 billion** in sales by the year 2000. The rapid development of optoelectronic technology over the last 5 years in Japan has been described by the Optoelectronics Industry and Technology Development Association (Ref 6).

Table 1. JAPANESE SEMICONDUCTOR SALES, 1985

TOTAL SALES	III-V	Si
SUBSTRATES	$50. million	$1.0 billion
DEVICES		
Discrete	$616. million*	$2.4 billion
ICs	—	$7.6 billion
Total Devices	$500. million	$10.0 billion

* Breakdown: Optical $546. million
Electronic $70. million

A breakdown of compound semiconductor devices sold in Japan in 1985 is provided in Table 2. In all cases listed, Japan holds a very large edge over the United States. This is primarily a result of the fact that these devices are used in large numbers in the consumer electronics and optical communications systems for which Japan dominates the world market. A number of interesting facts emerge from these data. The first is that the clear leader in sales is the relatively unsophisticated light emitting diode (LED), which outsells its nearest competitor in this table by nearly three orders of magnitude. Visible LEDs are used in large numbers for displays and indicator lights in consumer electronics, and infrared LEDs are used for many kinds of sensing devices, including camera auto-rangefinders. Thus, although the cost per device is small, a very large number of these devices find their way into the electronics industry. Another surprising fact is the very large number of visible laser diodes (LDs) that are sold; these are used in compact discs (CDs), a market which is anticipated to increase very rapidly in the next few years (Ref 7). Even in the area of optical communications, where infrared LDs are used, the Japanese have a large domestic market because the use of optical communications systems is widespread. Their devices are of very high quality so that, even in the United States, Japanese lasers at 1.3 microns are often preferred. For example, the Bell system has chosen to buy Japanese lasers for certain applications, and the Atlantic cable will use Hitachi lasers. It should be noted that there is a large difference in price between visible lasers used in CDs (≈$10 each) and infrared lasers used for communications (≈$1000 each). The big market in GaAs solar cells is satellite usage. Just as for optical devices, consumer electronics is again the major force for the sale of electronic devices. For example, the sale of Hall elements, which are needed in video cassette recorders (VCRs), dominates the electronic market by a large amount.

Table 2. III-V COMPOUND DEVICES SOLD IN JAPAN
(millions of units)

OPTICAL	1985	1990 (est.)
LEDs	3,800	11,700
LDs: Visible (CDs)	2.8*	11.4
LDs: IR (Opt. Comm)	.03	0.2
Detectors	.03	
Solar Cells	2.0	
ELECTRONIC		
μwave diodes	0.7	
FETs	7.5	11.7
Hall Elements	243	370

*U.S. estimates put this figure = 1/3 higher

As far as substrates are concerned (which, as shown in Table 1, represent about 10 percent of total semiconductor sales), it is estimated that the United States has about half of the substrate market, but that much of it is for internal company use (i.e., captive market) and is therefore not for sale. An example of this is the substrate production by AT&T Bell Laboratories.

COOPERATIVE RESEARCH IN JAPAN

How did Japan capture so much of the market in III–V semiconductor sales and take over the lead for semiconductors in general? This is a question that has been hotly debated in the halls and offices of industry in both the United States and Japan, and one for which there is no clear answer. Many people ascribe the growing dominance of Japan in the microelectronics industry to their imaginative use of cooperative research, particularly between industry and the Japanese government through MITI. I believe that this view tends to be exaggerated in the United States, particularly in terms of **present** achievements, but that the **long range** effects have hardly been felt, and will be very positive.

Table 3 gives a list of current (or recently completed) cooperative research projects in Japan; those dealing with III–V compounds are underlined for emphasis, and the number of companies participating in the project is given. In all cases, the project is of limited duration, with times ranging from 4 to 8 years. Total budgets are given for the lifetime of the project and for fiscal year 1985; in each case, MITI contributes a substantial amount of the budget. Although budget figures are not available in some cases (at least not to me), if one makes reasonable guesses about the level of support in those cases, one sees that an

appreciable fraction of $1 billion is being spent on research and development using this cooperative approach, and over $70 million last year alone (Ref 8). The cooperative projects listed in Table 3 are only those for microelectronics computer and communication research and for automated manufacturing; there are cooperative projects in many other areas as well. For example, the Japanese are making major efforts in biotechnology.

Table 3. JAPANESE GOVERNMENT PROJECTS RELATED TO COMPUTER AND COMMUNICATIONS RESEARCH AND DEVELOPMENT

				Budget($million)		
Project	Subject	Comp.	Lab	Time	Total	FY85
Optoelectr. Applied System	Optical Loc. Area Network	14 + ETL	OJL (9)	79-85 (OJL to 3/87)	75	14.6
Super-computer	MESFET HEMT JJ	6 + ETL		81-89	96	11.3
Fifth Generation Computer	Artific. Intell.	7+ETL, ECL, NTT	ICOT Res. Lab	82-91	?	20.0
Future Electron Devices	Superlatt. 3D Si Hard ICs	11 + ETL		81-87	?	6.3
"Inter-Operability"	Interop. between computers	info not available		85-91	63	0.1
Σ System	System software, maint.	info not available		85-88	?	12.5
Advanced Robot Technology	Robotics	ETL, MTL		83-90	83	8.3
Flexible Mfg. System	Manufact. Techn.	ETL, MTL		77-84	57	0.0
			TOTAL		≈600-700	73.1

The VLSI Project

How effective are these cooperative projects? To try to answer that question, let us look at the first of these cooperative projects (not listed in Table 3), the VLSI project. Information about the VLSI project is given in Table 4. The project had only a 4-year lifetime, from 1976–1980. It was established for a specific purpose, to respond to the domination of the integrated circuit memory market that the United States enjoyed; the emphasis, therefore, was on specific technology development, although the work was quite basic. Only five companies, listed in Table 4, participated in this project, along with the Electrotechnical Laboratory (ETL), a government laboratory in Tsukuba. Those companies contributed about 60 percent of the $300 million total budget for the project, while MITI contributed the other 40 percent. In this project as in other subsequent cooperative projects, however, many of the member companies claim they have actually spent twice this amount on the project work.

Table 4. THE VLSI PROJECT, AN EARLY EXAMPLE OF COOPERATIVE RESEARCH IN JAPAN

- 4 years: 1976-1980
- Develop VLSI Technology
- 5 Member Companies* plus ETL
- Budget
  - Companies: ¥42 billion = $180 million
  - MITI: ¥28 billion = $120 million
- VLSI Special Project Laboratory
  - Budget: ¥10 billion (≈15% of total)

* Fujitsu, Hitachi, Mitsubishi, NEC, Toshiba

A significant aspect of the VLSI project was the formation of a special project joint laboratory whose personnel came from the research laboratories of ETL and the five member companies. About 15 percent of the total budget was spent in support of this special project laboratory. Researchers from the five member companies worked together on specific projects, and at the end of their project they returned to their companies in good standing. This is made possible by the "lifetime employment" approach that is part of the Japanese system in large companies and would be much more difficult to do in the United States. The limited lifetime of these cooperative research laboratories was a very

attractive feature to the member companies, since the commitment made [illegible] research would be limited, and personnel would return at the end of the project. When the project lifetime ended, the doors of the special project [illegible] clanged shut, researchers returned to their parent companies, and the [illegible] equipment was divided up through sales to the highest bidder.

Much has been written about the effectiveness of these cooperative research projects. For example, Uenohara et al. (Ref 2) stated: "Clearly the VLSI project was a remarkable organizational innovation that essentially succeeded in engendering a new breadth of capability in the Japanese semiconductor industry." In another chapter of the same book, Weinstein et al. (Ref 2) provided a list of 22 specific new products and processes that resulted from the VLSI project. On the other hand, later in the same chapter, they state: "except for the work using liquid crystals, the Japanese did not appear to have made any major breakthroughs." Nevertheless, Weinstein et al. make a rather strong statement concerning the Japanese activity in VLSI: "By the end of 1981, the Japanese had captured 70 percent of the 64K RAM market and some industrial commentators declared that Japan had 'won' the battle for the memory market" (Ref 2). Recall that in 1976 Japan had little or no RAM capability! Clearly this astonishing progress cannot be ascribed solely to the VLSI cooperative research project; there was simply not enough time for its effects to find their way into the market place. However, this project does represent an important component of a massive Japanese effort to develop random access memories and has assisted Japan in maintaining an aggressive, competitive posture in this market. Furthermore, the focus which such a project represents has enabled their industry to set up a manufacturing capability for new products with extraordinary speed. This has also led to the development of high-quality process equipment. For example, one result of the VLSI project was the development of Japanese electron-beam exposure systems, which now dominate the world market.

Thus, the long range result of the VLSI laboratory appears to be a very positive one. Nevertheless, there is still some question as to whether or not the same effects would have been accomplished without the special project joint laboratory. There is a point of view, which was expressed to me by several of the managers of member companies that I visited during my stay in Japan, that, in fact, the money spent on these cooperative laboratories **might better be spent by the companies themselves,** so that more rapid progress could have been made within the member company laboratories in a framework of competition with other companies. This emphasis on **competition** rather than **collaboration** between the Japanese electronics companies came through over and over again in my conversations with their research managers.

This point was made clear to me in a humorous but emphatic way one night at dinner with one of these research managers. He said that he would often go to dinner with one or another colleague from a competing company; little would be said all evening about recent progress, they would part with much handshaking and bowing, and the next day he would read in newspapers about his friend's latest coup! Other managers have estimated that research interactions in Japan are about 80 percent competition and 20 percent collaboration. The competition is particularly severe in the area of recruiting the best young graduates into the company, since this is a longer range commitment than in the United States.

The Optoelectronics Applied System Project

The organization of the cooperative research project in optoelectronics was quite different from the VLSI project, as shown in Table 5. In this case, the project lasted for 7 years, from 1979–1985, and it was focused on the research and development of an optical measurement and control system for a specific industrial environment. There are 14 member companies in this project, plus ETL; these are listed in Table 6. The original plan was that the project would last 8 years, and MITI's budget would be 18 billion yen (about $75 million (Ref 8)); this was later reduced to 7 years, with an expenditure of 16 billion yen by MITI. The project also included a special project joint laboratory, the Optoelectronics Joint Research Laboratory (OJL), which has received a great deal of favorable publicity (Ref 9–11).

Table 5. THE OPTOELECTRONICS APPLIED SYSTEM PROJECT, AN IMPORTANT CURRENT EXAMPLE OF COOPERATIVE RESEARCH IN JAPAN

- 7 years: 1979-1985
- R&D of Optical Measurement and Control System
- 14 Member Companies + ETL
- MITI Budget
  - TOTAL: ¥16 billion = $67 million
  - FY85: ¥3.5 billion = $15 million
- Optoelectronics Joint Research Laboratory (OJL)
  - 6 years: 1981-1986 (→ March 1987)
  - Generic Materials Technology
  - 9 Member Companies + ETL
  - MITI budget: ¥6 billion = $25 million (≈1/3 of total)

Table 6. PARTICIPANTS IN THE OPTO-ELECTRONIC APPLIED SYSTEM PROJECT (MEMBERS OF OJL ARE UNDERLINED)

GOVERNMENT LABORATORY

- Electrotechnical Laboratory (ETL)

PRIVATE INDUSTRY LABORATORIES

- Fuji Electric
- Fujikura Cable
- Fujitsu
- Furukawa
- Hitachi
- Matsushita
- Mitsubishi
- NEC
- Nippon Sheet Glass
- Oki
- Shimadzu Seisakusho
- Sumitomo
- Toshiba
- Yokogawa Electric

OJL was started in 1981; it will have a lifetime of 6 years to March 1987, with a significantly reduced budget (company funds only) during the last year. OJL's mission was directed even more towards basic research than was the VLSI laboratory; OJL was charged with working on generic materials technology that would be of use to all of the companies in developing III–V devices. Thus, OJL did not work on devices themselves but worked on a broader range of basic materials research which the member companles needed for device development. This approach had a number of advantages; for example, the companies did not have to give away any of their processing and fabrication secrets that are so important in device development and manufacturing, and at relatively low

cost, they could participate in materials research that might be considered too expensive for any one company. Along with ETL, 9 of the 14 members of the Optoelectronics Applied System Project joined OJL, and MITI's contribution to OJL's budget was about one-third of the total. A breakdown of that budget is given in Table 7, where it can be seen that nearly 60 percent of MITI's funds were spent on capital equipment for the laboratory. Thus, the effect of MITI's sponsorship of this project was that OJL was a very capital-intensive laboratory; the management of OJL assembled the most impressive collection of high-technology, materials-oriented, state-of-the-art equipment that I have ever seen. The rather small space rented from Fujitsu in their Kawasaki facility was literally crammed with machines for sophisticated crystal growth, such as molecular beam epitaxy (MBE) and metal-organic chemical vapor deposition (MOCVD), and the finest characterization and analysis equipment available. In fact, the ratio of occupied to unoccupied floorspace was so large that this somewhat overweight middle-aged professor found it difficult to get around the lab without danger to elbows and shins!

Table 7. OJL BUDGET BREAKDOWN

• MITI	
- Equipment	$14 M
- Other[a]	$11 M
Sub-total	$25 M
• MEMBER COMPANIES	$12.5 M
TOTAL	$37.5 M

(a) Includes ≈50% of research salaries

It is interesting to compare certain aspects of the two special project joint laboratories that I have just described, the VLSI lab and OJL. This is done in Table 8. As mentioned before, the VLSI lab had a 4-year lifetime, whereas OJL will be in operation for 6 years. On the other hand, the number of technical staff for the VLSI lab exceeded 100, more than twice the staff of OJL, so that the total number of man-years for VLSI was about one-third greater, whereras the total budget was about the same. The VLSI lab was far more concentrated, and represented a much bigger effort for a short period of time to develop technology, than the more long-range materials research that has been carried out by OJL. The results of these differences are clear from the number of patents, publications, and papers that were forthcoming from these laboratories. In Table 8, it is clear that the VLSI laboratory concentrated on patents,

receiving about 450 in a period of only 4 years, whereas more publications have already come out of OJL, and its publication rate is rapidly increasing in its final year. Thus, OJL was a considerably more basic research endeavor, which may contribute to its effectiveness; although it is still in operation, nearly everyone with whom I have spoken considers it to be a resounding success. A measure of that success is the plan for a second generation optoelectronics "project" with a 10-year lifetime (see below).

Table 8. COMPARISON of VLSI LABORATORY and OPTOELECTRONICS JOINT RESEARCH LABORATORY

	VLSI Lab	OJL
No. of Technical Staff	110	50
Years	4	6
Total Budget	$40M	$37.5 M
Patents	450	130
Papers, Publications	460	510

The Optoelectronics Applied System Project had as its goal the research and development of an optical measurement and control system that would be applied to a specific industrial need. It was decided that the first application would be to an oil refinery plant for a number of reasons:

- Such plants tend to be extremely large and yet closed systems, so that an optical system would be appropriate.
- There is a need for a large number of sensors for process control, and these sensors could be optical devices.
- The use of electrical energy for measurement and control raises very serious safety issues.
- Not insignificantly, there was funding available to MITI through the tax base provided by the oil companies.

A total system was targeted for introduction in the Kansai area (Osaka, Kobe, Kyoto) in the fall of 1985. It was actually introduced in the Mizushima Oil Refinery Plant of the Japan Mining Company (Nihon Kogyo)—located about 1 hour from Osaka—during the month of January 1986.

The optical system was divided into a number of subsystems, which are listed in Table 9. These subsystems have names like "Complex Process Data Subsystem," "Data Control Subsystem," "High-Speed Image Data Subsystem," etc., all of which convey relatively little meaning to me. However, each of these subsystems is centered around a specific optoelectronic device that has a

great deal of meaning. Examples are: a multiwavelength (five different wavelengths) indium phosphide distributed feedback (DFB) semiconductor laser, a GaAs phase-locked laser array for very high output power, a visible emitting laser diode, etc. In each case, the subsystem device was given to a specific company to develop. The details for these assignments are shown in Table 9. Two of the subsystems listed in Table 9, the High-Speed Process Data Subsystem and the High-Quality Image Data Subsystem, have actually been demonstrated in the oil refinery plant; the others have been demonstrated in the laboratories of the responsible companies. In addition to these subsystems, many optical fiber sensors have been developed through this project.

Let us turn to a few of the devices listed in Table 9 to estimate the progress that individual companies have made on their assigned devices. Before doing this, however, it is appropriate to make an aside.

Table 9. THE FIVE SUBSYSTEMS OF THE OPTOELECTRONICS APPLIED SYSTEM PROJECT

- Complex Process Data Subsystem
  - *Multi-wavelength Laser*
    - 5-wavelength InP DFB
    - Toshiba
- High-Speed Process Data Subsystem
  - *High Power Laser Diode*
    - GaAs phase-locked laser array
    - Mitsubishi
- Data Control Subsystem
  - *Integrated High-Speed Laser Diode*
    - Integrated GaAs driver, modulator, detector
    - Hitachi
- High-Quality Image Data Subsystem
  - *Highly Integrated Multi-Channel Optoelectronic Switch*
    - Sophisticated OEIC
    - Fujitsu
- High-Speed Image Data Subsystem
  - *Visible-Emitting Laser Diode*
    - InGaAlP
    - NEC

It is not the simplest task to judge the quality of the research of a group of people, or for that matter, of a large company or even a country. One measure that is frequently used (particularly by the Japanese) is the number of presentations or publications that have been produced by the particular group in question. Although it is clear that this approach has its limitations, it is nevertheless useful, particularly if the yardstick employed is an international conference or a major journal with a critical selection process. A fairly recent conference that could be considered appropriate for compound semiconductor optoelectronics was the International Conference on GaAs and Related Compounds, held at Karuizawa, Japan, in September 1985. Clearly, the host country has an advantage at such an international conference; for example, the French had more than their usual number of papers when this conference was held in Biarritz the year before. However, it was the opinion of most of the foreign attendees with whom I spoke that the Japanese contributions totally dominated the Karuizawa conference, and that the progress they had made in both the device and materials areas was no less than spectacular! It seemed that a long-range commitment to III-V compound technology made some years ago by the large electronics companies in Japan had paid off handsomely; the results came pouring out at Karuizawa. It was clear in addition that these same companies had made significant progress on their part of the optoelectronics project as given in Table 9. A few examples should prove the point.

- Both Toshiba and NEC announced a high-quality visible laser at the Karuizawa conference, capable of competing with the Xerox PARC device that has been the leader in high-power visible emission. Their "scheduled" presentations were both on crystal growth, but device results were announced because of a post-deadline paper by Sony describing progress on a laser using the AlGaInP/GaInP lattice-matched system grown by MOCVD. The active layer was undoped $Ga_{0.52}In_{0.48}P$, emitting light at a wavelength as low as 620 nm (bright red). Sony achieved a room temperature threshold of 2×10^4 A/cm^{2}µm, and CW lasing to T = 33 °C. Not to be outdone, the NEC presentation included a statement that NEC (responsible for the visible laser in the optoelectronics project, see Table 9) had achieved 4 kA/cm^2 and CW lasing to 50 °C with the same material system. I think there are two points to be made here: considerable progress had been made on visible lasers in Japan (an area where the U.S. had been leading), and this was done with a high level of competition between Japanese companies. Both of these points will be made again in this report.

- Fujitsu, responsible for a highly integrated multichannel optoelectronic switch, indulged in an frenzy of acronyms with its paper on the "SLBGRIN-SCH-SQW-RW Laser" (strained-layer-buffer graded-index separate-confinement-heterostructure single-quantum well, ridge-waveguide laser)! By combining a technology already recognized for its low-threshold potential ("GRIN-SCH" laser with a single quantum well) with a strained-layer buffer, Fujitsu was able to achieve a threshold current as low as 3 mA, 30 mW output per facet, differential quantum efficiency exceeding 80 percent, less than 2 percent change in output power per 1,000 hours operating time (tested for 4,000 hours at the time of the conference), and nearly single longitudinal mode. More significant than these excellent characteristics of the discrete device, however, was

the monolithic integration of four of these lasers with detectors to form a four-channel laser/photodiode array, all having very similar operating characteristics. A most impressive display of technology!

- Finally, Hitachi (responsible for integrated high-speed lasers) dazzled the audience with the monolithic integration of no less than 14 separate devices in the form of a source-receiver circuit using a multiquantum well (MQW) laser with mirrors fabricated by reactive ion beam etching (RIBE) in order to integrate the laser with other devices on the chip. The rest of the circuit consisted of a driver circuit made by implant technology, having a switching time of 130 psec, and a receiver circuit using a GaAs PIN diode in combination with a high-impedance amplifier (1 FET) and a transimpedance amplifier (3 FETs). The laser had a threshold current of 31 mA, and its light current performance characteristics were identical with lasers made from the same chip having cleaved mirrors, indicating the high quality of the etched mirrors. (This RIBE technology, by the way, is one of the areas of intense research at OJL, as we shall see below.)

These few examples should suffice to suggest that the electronic companies are indeed making swift progress on a variety of optoelectronic devices and associated materials problems, and in particular are nearing completion of the specific devices listed in Table 9. More will be said about the research activities of individual companies in a later report; attention here should now be focused on the special project laboratory for the optoelectronics project, the Optoelctronics Joint Research Laboratory in Kawasaki.

OPTOELECTRONICS JOINT RESEARCH LABORATORY (OJL)

As mentioned above, 9 of the 14 companies that are members of the Optoelectronics Applied System Project have agreed to participate in the special project laboratory that was established in 1981, along with the Electrotechnical Laboratory (ETL). Some of the organizational and administrative details of OJL have already been discussed in this report; it should be clear that OJL is a unique, extremely well-equipped facility working on generic technology research that is of interest to all the member companies, but which allows participation of the companies without compromise of privileged information regarding processing and fabrication techniques and device design concepts. The choice of material for this research has been almost exclusively GaAs (and related, lattice-matched compounds such as AlGaAs). This has been done because OJL's long-range materials research focuses on the concept of optoelectronic integrated circuits (OEICs), that is, the integration of optical devices with high-speed electronic integrated circuits. Since the technology for high-speed electronic devices is expected to be dominated by GaAs for some time in the future (GaAs MESFETs now, high-mobility devices using two-dimensional electron gases in the future), it was felt by the organizers of OJL that focusing on GaAs would be appropriate (Ref 12).

In what follows, I would like to highlight some of the research accomplishments of this laboratory. To do this, it is instructive to look at the structure of OJL in terms of its research group membership, since I feel that this contains a great deal of information concerning the individual company interests. A summary for all six research groups is given in Table 10.

Table 10. ORGANIZATIONAL STRUCTURE OF OJL

DIRECTOR-GENERAL:	T. Iizuka
TECHNICAL DIRECTOR:	I. Hayashi
RESEARCH PLANNING:	M. Hirano
ADMINISTRATION:	A. Okamura

GROUP:	Bulk Growth	FIBI	Epi Growth	Surf. Phys.	Fabr. Tech.	Charact.
Manager: & company:	Fukuda Toshiba	Hashimoto Fujitsu	Ishii Mitsub.	Nakashima Hitachi	Asakawa NEC	Ishida NEC
	Number of Members*					
ETL						1
Fujitsu	1	4				1
Furukawa	1				1	1
Hitachi	1			3		
Matsushita		1	1	2		1
Mitsubishi	2		3			2
NEC	2		2		2	1
Oki			1	2		
Sumitomo		1	3	1		
Toshiba	3		1			1
TOTALS:	10	6	11	8	3	8

* Information from Fall, 1985. Some researchers have subsequently returned to their member companies because of the limited remaining lifetime of the laboratory

Group 1: Bulk Crystal Growth

It is clear that Toshiba has a strong interest in bulk growth of high quality GaAs, although many other companies are represented in this effort. Under the capable leadership of Dr. T. Fukuda of Toshiba, this group is one of the best in the world at developing advanced techniques for bulk growth using the liquid-encapsulated Czochralski (LEC) technique. Some of their accomplishments have been:

- The use of magnetic-field techniques (MLEC) to achieve very uniform, striation-free material with a consequent reduction in dislocation density.

- The development of very low temperature gradients to reduce dislocation densities to well below 1000 cm^{-2} without the use of In doping, which has been used in other laboratories, and which it is felt would be better not done. In order to grow in a low temperature gradient while maintaining visual observation of the solid/liquid interface (considered to be essential for good control of crystal growth), this group developed a unique x-ray imaging system.

- The development of As injection into the melt to accurately control the melt composition and hence the uniformity of wafer resistivity. This is done through the control of the deep compensating center referred to as EL2, for which there is a mass of evidence that an As-antisite defect is involved (and hence requires a slight excess of As in the crystal).

Using these three techniques in appropriate combination, OJL currently has the best control over defect introduction and compositional control and uniformity of any laboratory in the world, and hence is in a strong position to carry out a systematic investigation of the principal defects in this material (an activity which is currently in progress; see Group 6). These improvements in GaAs bulk growth are critical to the development of GaAs ICs as well as the optoelectronics industry.

In addition, some work has recently been initiated on the bulk growth of InP, using liquid P as the encapsulant. This is accomplished by allowing vaporized P to condense on the walls of the growth vessel and run down onto the In melt, encapsulating it with liquid P. OJL was the first laboratory to try this approach, and they have succeeded in growing material at considerably lower pressure than must be used for direct synthesis (500 atm). A preliminary report of this work was recently given at the Electronic Materials Conference, University of Massachusetts, 25 June 1986.

Group 2: Maskless Ion Implantation (FIBI)

As can be seen from Table 10, this activity at OJL is dominated by Fujitsu; even the group leader, Dr. H. Hashimoto, comes from Fujitsu. At the conclusion of the optoelectronics project, Fujitsu will clearly have a large lead in what could amount to a very important technology in Japan. Maskless ion implantation features a focused ion beam implanter (FIBI) coupled through a common ultrahigh vacuum (UHV) system with a molecular beam epitaxy (MBE) crystal growth system. An analysis chamber with Auger electron spectroscopy and mass spectroscopy are also part of the UHV system. The FIBI machine can implant B, Be, or Si (for doping III-V compounds), and Ga (for damage studies, superlattice destruction, and machine testing), with a spatial beam resolution of 0.1 micron into a UHV surface, followed by MBE growth of additional layers, burying the implanted species in whatever way is desired. The implications of such a technology are tremendous for the development of OEICs. For example, complicated patterns of p-n junctions can be made with precise three-dimensional control of their position, buried-laser active layers can be directly implanted (assuming

that implant damage can be eliminated; see below) using extremely small dimensions, leading to the possibility of microlasers having submilliampere threshold currents. Furthermore, these structures (both optical and electronic) can be placed at will anywhere on a wafer, making possible a high level of opto-electronic integration. The potential of this coupled FIBI/MBE system is extremely great, and the investigation of its capabilities represents one of the major contributions of OJL.

Just how good is this system for making defect-free structures? Several experiments have been designed at OJL to answer this question. In one experiment, a 2.4-μm layer of Be-doped GaAs ($p = 1 \times 10^{16}$ cm^{-3}) was grown by MBE, followed by implantation (using FIBI) of Be at a dose of 1×10^{13} cm^{-2}. This corresponds to a Be concentration in the implanted region approximately two orders of magnitude greater than in the conventionally doped layer. Finally, a second MBE layer of Be-doped GaAs (also $p = 1 \times 10^{16}$ cm^{-3}) was grown to cover the free surface that received the Be implant. This second growth was done in two different ways. In one case, the overgrowth was done after removing the sample from the UHV system, so that the normal defect incorporation at a free surface exposed to atmosphere could take place. In the second case, the entire process was carried out in UHV. Photoluminescence was then measured for both cases by scanning the luminescence excitation beam across a cross section of the two-layer sample. In the case of all-UHV sample preparation (made possible by this remarkable apparatus), no reduction of luminescence intensity was observable at the regrowth interface, indicating that a defect-free interface resulted from this procedure. Furthermore, after appropriate annealing of the implant damage, the region implanted with Be showed a strong increase in luminescence due to the Be acceptor, as expected. In the case where the regrowth interface was exposed to air, however, a strong decrease in luminescence efficiency was noted at the position of the interface, showing the usual effect of defect incorporation at such an interface. The results of this experiment are therefore extremely encouraging, suggesting that truly defect-free interfaces can be obtained after implantation when the entire process is carried out in a UHV environment.

Although OJL is not device-oriented, as described above, no Japanese researcher worth his soba can resist the construction of a simple device given the potential of this facility, and OJL researchers are no exception! Several laser devices have been fabricated using maskless ion implantation. By implanting the active layer following standard processing (i.e., cleaved mirrors, etc.), lasers with reasonable operating characteristics have been realized. More recently, novel lasers have been constructed using superlattice disorder (or suppression thereof) by enhanced diffusion; these devices will be described below in conjunction with Group 4.

Group 3: Epitaxial Growth

This group is dominated by two companies, Mitsubishi and Sumitomo, both from the Kansai area of Japan. The group leader is Dr. M. Ishii of Mitsubishi. It is interesting that Sumitomo, long the world leader in bulk GaAs substrates, considers epitaxial growth so important. That leadership is currently threatened by the large number of Japanese companies—as many as eight of them—now getting into bulk growth. In addition to Sumitomo Denki (Electric), there are,

for example, Sumitomo Kinzoku Kozan (Metal Mining), Mitsubishi Monsanto, and Mitsubishi Kinzoku (Mining). It is clear that Sumitomo and Mitsubishi have a lot at stake in keeping current with crystal growth technology!

The activities of this group are varied, and can only be highlighted here. Both MBE and low-pressure metal-organic chemical vapor deposition (MOCVD) are investigated. Two themes that run through much of this work are the investigation of growth over patterned wafers for new active device configurations (particularly those that will lead to a planar technology) and the use of novel configurations of quantum wells and superlattices to tailor the properties of devices. Neither of these ideas were originated by the Japanese, but their capital equipment advantages allow them to pursue these ideas in conjunction with other, unusual capabilities, such as FIBI. Growth over patterned substrates has led to the growth of 1-μm stripe-width lasers grown by MBE over grooved substrates (called PGS laser, for pair-groove-substrate) and various MOCVD growth morphologies (including planar) over etched substrate grooves with very different orientations. OJL has MBE machines from most of the major suppliers (Varian, Riber, and VG), as well as several home-built machines. The opportunity for making comparative assessments in this laboratory is therefore great. In addition to a strong effort on the epitaxial growth of the GaAs/AlGaAs system, Dr. Ishii is considering working on P-based compounds involving the general AlGaInAsP system, for which good results have been obtained at Sony, NEC, and Toshiba using MOCVD. He is obviously aware of the problems of growing P compounds by MBE.

OJL has been building a gas source MBE system for nearly 2 years, and results are just beginning to come out. Using triethylgallium (TEG) and arsine, they achieved the lowest background acceptor concentration produced to that date (late 1985): $p = 3 \times 10^{14}$. Just recently, they have made the first observation of the doping enhancement of MBE GaAs using a pulsed excimer laser.

This group has also interacted closely with other groups at OJL on the development of novel structures such as short-cavity lasers and disordered superlattice lasers, which will be described below.

Group 4: Applied Surface Physics

This is the "Hitachi" group, although both Matsushita and Oki (new to III-V technology, but growing rapidly) have strong representation. The group leader is Dr. H. Nakashima of Hitachi. This group works on a large variety of problems, some of which are among the most fundamental problems under investigation at OJL: surface physics and chemistry of Au (and other metals) on GaAs; properties of LaB_6, a material which may make a superior Schottky gate to GaAs; studies of various interfaces between insulators, metals, and semiconductors using a wide variety of techniques including Rutherford backscattering; proton-induced x-ray emission (PIXE); and x-ray photoelectron spectroscopy (XPS). However, Dr. Nakashima was a Hitachi laser researcher, and he continues to pursue novel laser concepts within the context of his group and its interactions elsewhere in the laboratory.

One of the most promising of these activities is the investigation of superlattice disordering by enhanced diffusion of Zn and Si. Both conventional diffusion of Zn and the diffusion of Si after implantation (conventional and FIBI) are being investigated. Narrow stripe-width (2.2-μm) lasers with reproducible light-current characteristics and 25-mA thresholds have been fabricated by diffusing implanted Si through a multiquantum well (MQW) layer to produce the lateral confinement for the MQW active layer. When the same procedure is used at the mirrors of a laser, separating the mirror from the active layer, a significant increase in output power is achieved before the threshold for mirror damage is reached. More recently, an even more interesting effect has been observed in Japan and used for device formation at OJL. It appears that enhanced diffusion (and hence, superlattice disorder) takes place only when the carrier concentration exceeds a certain level. If the material is co-doped (for example, by implanting Be), no disorder takes place, whether the Si is there by implantation or conventional doping. The most recent laser structure fabricated at OJL makes use of this principle to prevent the disorder of a heavily Si-doped superlattice layer by implanting Be into it. The laser is thus made entirely by maskless techniques.

In addition to the use of superlattice disordering techniques to pursue new device structures, Group 4 is also interested in the fundamental diffusion mechanisms involved. Some very interesting, though not understood, phenomena are currently being investigated. For example, enhanced diffusion occurs when Si is introduced either by conventional implantation or by FIBI. However, there is a "dose window" when FIBI is used. That is, not only does the dose have to exceed a certain value (to achieve a concentration of about 10^{18} cm^{-3} or more, as observed for conventional implants), but if the dose is too great using FIBI, no disorder results. It is not clear if this is a dose or dose rate effect, although the latter seems to be the case. Further, investigations are underway and should prove important for any maskless technology.

Group 5: Fabrication Technology

This "group" is not really a group in the usual sense, with only three members; however, it constitutes a strong effort in dry etching technology at OJL, under the leadership of Dr. K. Asakawa from NEC. The acting head of this group is Dr. M. Hirano of ETL, who also serves as the laboratory administrator for research planning. The emphasis here has been on reactive ion beam etching (RIBE) for the microfabrication of a variety of device structures necessary for the formation of OEICs. Although some of the earliest research using RIE techniques was reported by researchers at Bell Laboratories (some of whom are now faculty members at UCSB), the OJL work has made some of the more recent advances in perfecting this technique, with important applications to device fabrication. For better control of the etching characteristics, particularly the directionality of the incident etching plasma, a "beam" of ions is extracted from an electron cyclotron resonance plasma source and directed at the sample under UHV conditions that are fully compatible with other in situ processing techniques under development at OJL, such as the maskless implantation described above. By adjusting the source pressure and beam extraction energy, the ratio of chemical/mechanical etching can be controlled so as to minimize surface damage, or maximize etch rate, as required. For example, it has been possible to achieve equal etch rates for GaAs and AlGaAs surfaces, so that no discontinuity occurs when etching through multiple layers to differing composition of

these materials as encountered in quantum well or superlattice structures. Finely patterned structures have resulted with extremely smooth vertical walls, or walls with arbitrary angles with respect to the substrate, by varying the relative orientation of the substrate in the etching system. Using such etching techniques, semiconductor lasers have been fabricated with smooth, vertical etched mirrors; the lasers have operating characteristics essentially identical with lasers made with conventional cleaved mirrors. This group is also exploring the use of electrically neutral but chemically reactive radical species for anisotropic etching and damage-free surface polishing.

Recent device work using RIBE in conjunction with the epitaxial growth techniques developed in Group 3 has led to research on very short cavity lasers. The mirrors are made by RIBE, so that the length of these lasers is not limited by mechanical difficulties in cleaving. Cavity lengths as short as 20 μm have been produced, with active layers formed by the PGS technique. At present, the threshold current for such lasers is high, but the researchers developing these techniques have found that there is a strong dependence of the device threshold current on the number and thickness of the quantum wells used for the active layer; work is presently underway to optimize these parameters.

Group 6: Materials Analysis and Characterization

Unlike most of the other groups, which tend to be dominated by one or two of the member companies, the characterization group has eight members from seven different companies. Everyone wants to be able to determine the quality of their material! Under the leadership of Dr. K. Ishida from NEC, the major activity of this group is the characterization of bulk LEC material grown by Group 1. In fact, because of the strong concentration of characterization expertise (photoluminescence, DLTS, EPR, TEM, electrical measurements, etc.) in the same laboratory having so strong an effort in bulk growth of GaAs, I believe that OJL stands at the threshold of making a major contribution to the understanding of the principal defects in this material, such as the deep, compensating defect known as EL2, which is responsible for the semi-insulating behavior of undoped GaAs. This is probably the only laboratory in the world currently capable of mounting a systematic study of bulk GaAs with carefully controlled changes in stoichiometry; current activity involves the investigation of the effect of changes in stoichiometry on lattice parameter changes and extended and point defect densities. Very recently (reported at the International Conference on Semi-Insulating III-V Compounds, held in Hakone in May 1986), the group has reported the first systematic study of the lattice constant of bulk GaAs as a function of stoichiometry. They found that the lattice constant increases with the amount of As added to the melt of the LEC-grown material, suggesting that the excess As enters the lattice interstitially, a fact that is consistent with recent ENDOR results (also reported at Hakone) that suggest EL2 is a complex consisting of an As-antisite defect (As on a Ga site) and a nearest neighbor As interstitial.

Another very recent and very important result from this group involves transmission electron microscopy of GaAs grown on Si, one of the more fashionable problems of moment in epitaxial crystal growth. The importance of being able to grow high-quality GaAs on Si substrates is obvious—such a technology makes possible the combining of the best of both worlds, high-speed

optoelectronic devices in GaAs with the current sophisticated VLSI technology of Si. Many groups in Japan, Europe, and the United States are working on this problem. One such group, at Oki Electric, has succeeded in making device-quality GaAs by first growing an amorphous layer of GaAs on Si at a very low temperature (too low for single-crystal growth), and then increasing the growth temperature to grow the final (device-quality) layers. Excellent results have been obtained by Oki using this approach. Ishida's electron microscope work, published in the Japanese Journal of Applied Physics in April of this year and reported at the Electronic Materials Conference at the University of Massachusetts in June, shows that atoms in the amorphous buffer layer have approximately the correct spacing for the GaAs crystalline lattice, and that after the high temperature growth of the second layer, the amorphous layer has recrystallized with the proper atomic spacing (if the substrate was properly cleaned). Stress is relieved in this process by the creation of misfit dislocations that run parallel with the layer, and hence do not propagate into the second layer grown. Thus, the mechanism for growth in this case appears to be quite different than that usually obtained for epitaxial GaAs, explaining the unusual results reported by Oki.

The Grand Finale!

At this point it should be clear that truly innovative materials and processing research is underway at OJL, and that progress has been significant during the limited lifetime of this laboratory. As was the case with the VLSI project, it appears that Japan will go from a position behind the United States to virtual domination of the optoelectronic device market during a time span only a little longer than the lifetime of this cooperative project. During the final months of the laboratory (now scheduled to close its doors at the end of the 1986 fiscal year, 31 March 1987), OJL is attempting a daring and truly synergistic experiment which will combine much of the expertise described above. During my last month at the laboratory, a huge UHV system was assembled that incorporated not only the focused ion beam implanter, MBE, and the analysis chamber described above, but also a new focused ion beam **etching** (FIBE) system, a radical gun for defect-free surface cleaning, and an electron beam annealing system designed to eliminate the damage resulting from FIBI. The FIBE system uses a focused Ga ion beam, with the introduction of Cl free radicals to assist in the etching. This massive vacuum system should be able to "do it all," complete in situ crystal growth, maskless implantation and/or etching, implant damage anneal, surface cleaning, and analysis of the results at any stage of processing, all within a UHV environment! Nothing like this has been (or could be) attempted anywhere else in the world! Dr. Izuo Hayashi, technical director of OJL and my host during my visit to OJL, admits that the problems in getting all the components of so complicated a UHV system to work at the same time may be insurmountable. However, should they succeed, the implications are enormous for the future of optoelectronic integrated circuits—all the growth, fabrication, and processing steps could be done in situ in one system, in a completely maskless way, without the need for photolithography, wet chemical processing, or exposure to any other hostile environment! A truly remarkable achievement. Even if success is not realized during the limited remaining lifetime of this laboratory, there will certainly be follow-through within industry.

COLLABORATIVE RESEARCH—OJL AND ITS MEMBER COMPANIES

The main thrust of the above discussion should be clear--the Optoelectronics Applied System Project, and in particular the special project joint laboratory known as OJL, is seen through the eyes of most foreign observers as an extremely successful government/industry cooperative venture. What is the view of Japanese researchers themselves, and how do members of different and highly competitive companies manage to carry off a collaborative activity of this kind? I have already addressed some of these questions briefly in the introduction to this paper, but much more can be written. Although there are no definitive answers, a few specific points can be made.

Success of the Optoelectronic Project

The Japanese themselves consider the Optoelectronics Applied System Project to be a highly successful one. In particular, the government sponsors at MITI have agreed in principle to the establishment of a second, follow-on project in optoelectronics, with a longer lifetime. The (rather sketchy) details as currently known will be given below; suffice it to say that this decision is a strong endorsement of the importance of optoelectronics and the contribution of the project to this technology. It might still be argued by some company managers that they could have proceeded more efficiently if simply given an equivalent amount of funds, but that argument seems to be lost in the political/ economic climate of technology in Japan. Thus, there will be another optoelectronics project in Japan!

OJL Researchers and Their Interactions

Company loyalties and Japanese group dynamics make a research arena at a laboratory like OJL a complicated one. It is clear that the "lifetime" employment policy of all large Japanese companies provides an advantage for a limited lifetime laboratory such as OJL. That is, the guarantee of a responsible position in the parent company at the end of an assignment at OJL makes it attractive for experienced researchers to take a position there on a temporary basis. Similarly, the companies themselves are much more willing to send their better researchers than would be the case in the United States; a case in point is the MCC, which was initially intended to be staffed by scientists on loan from member companies, but for which a significant fraction of the research staff had to be recruited from the open market. Another factor that contributes to the quality of the research staff at OJL is the redundancy built into the industrial research laboratories--a good researcher in a particular field can more easily be spared (for a limited time) because there are others willing and able to work on that project. Nevertheless, Dr. Hayashi, the technical director of OJL, admitted that he had to carefully screen all new proposed personnel assignments to the laboratory, and in a few cases rejected the researcher proposed by his company.

Although company loyalties remain strong, and the researchers return to their parent companies relatively often to report their progress, it seemed to this observer that equally strong, new loyalties had been forged within OJL. The importance of the group, and accompanying respect for the authority of the group leader, was very evident at OJL. Groups met frequently in both formal and informal situations; for example, they would have dinner and drink beer or

sake together in a relaxed but informative fashion about once a week. Since the laboratory focus was on generic materials technology of use to all the member companies, and not on devices, there was no need for a high level of inter-company competition, so that communication between researchers was very good. At times when device ideas were investigated, or the quality of the materials was tested by fabricating and evaluating devices made on these new materials, such work was done within the laboratory of the appropriate (i.e., most suitable) member company. Another advantage to the individual researcher of an assignment to OJL is the fact that such an assignment often carried with it an opportunity to do more basic research than had been the case within the parent company.

Technology Transfer to the Member Companies

A number of mechanisms have been established to transfer technology to the member companies. These include (in order of increasing detail of the information transferred): conference papers (which are in the public domain), an annual meeting of the optoelectronics project (at which brief progress reports are given), a written annual report to the project members (considerably more detailed), quarterly meetings with member companies (at which certain research areas are chosen for in-depth presentations), research collaborations, patents, and written technical reports on specific research areas. These reports may be the natural consequence of the completion of work in a specific area, or they may be a response to a specific company request for technology transfer. Examples of the latter are referred to as OJL Technology Transfer (TT) Reports. MITI clears all such reports and owns the patents arising from them.

At present, the member companies are interested in OJL TT reports on a number of subjects; negotiations are underway between MITI and several companies, who want the royalty-free use of patents which MITI owns (through the optoelectronics project). The companies may have to pay a small percentage of the income derived from the patent, if they obtain a detailed TT report, which describes the so-called "know-how" that is essential to the utilization of a new idea.

To date, much of the technology transfer that has taken place has involved bulk crystal growth (Group 1), so many of our remarks will refer to that area. Some examples of techniques that are under negotiation for the transfer of technology developed by this group are:

- computer-automated crystal shape control
- magnetic field LEC (i.e., MLEC)
- arsenic injection into the LEC growth chamber to control melt composition
- dislocation control through the use of a low temperature gradient

The two best examples of technology transfer that have already been achieved involve an infrared topograph system and the standardization of wafer characterization; in both cases, the characterization group (Group 6) worked

closely with the bulk crystal growth group to develop these technologies. The infrared topograph system developed for the inspection of GaAs wafers for internal defects was made available to Hamamatsu Photonics Co. (not a member company). The system is now commercially available, selling for about $33,000. As of the first of the year, 5 of these units had been sold, and another 20 sales were expected. MITI receives a royalty of about 1 percent of the price of each machine. In the case of the standardization of wafer characterization, six companies have agreed to make identical measurements (resistivity, Hall mobility, carrier concentration) on samples taken from the same slice and to provide their results to OJL for comparison.

There are at least eight ongoing research collaborations between OJL and the member companies. The standardization of wafer characterization involves six member companies, as mentioned above. Hitachi is actively working with OJL to characterize single crystal substrate material by (a) precise measurements of the lattice constant of the wafer and (b) the performance of semiconductor lasers fabricated on epi layers grown on these wafers. In the former of these collaborations, the results obtained by Hitachi were so promising that OJL purchased the equipment to do precise lattice-constant measurements in-house; in the latter collaboration, n-type LEC substrate material was used for lasers for the first time, and Hitachi wants detailed information regarding the growth conditions. A similar collaboration is underway with Mitsubishi, whose researchers are using transverse junction stripe (TJS) lasers to characterize semi-insulating (SI) substrate material. Fujitsu is collaborating with OJL to characterize doped layers in SI substrates produced by ion implantation. Toshiba is interested in the use of dislocation-free substrates for the manufacture of LEDs on epi layers grown by MOCVD, and Furukawa is interested in MOCVD epi-growth on In-doped SI substrates for device application. Finally, five companies (Fujitsu, Furukawa, Mitsubishi, NEC, and Sumitomo) are working with OJL on the standardization of Hall measurements on SI GaAs wafers.

All of the collaborations described above are related to the Optoelectronics Applied System Project. There are also some collaborations with companies involving the "Supercomputer" national project. For example, OJL researchers are involved with Fujitsu and Oki on high electron mobility transistors (HEMTs), and with Hitachi, Mitsubishi, NEC, and Toshiba on field effect transistors (FETs).

Cooperative Research with Universities

OJL researchers are also involved in a number of collaborations with university professors. Examples include Professor Komatsu and Professor Sumino at Tohoku University, Professor Kobayashi at Toyama University, Professor Nishinaga at the University of Tokyo, Professor Matsumoto at Keio University, and Professor Kukimoto at the Tokyo Institute of Technology. In addition, a number of professors serve on OJL's advisory board. All of these collaborations were established on the basis of mutual interest; some were initiated by OJL researchers and some by the faculty members. However, OJL (as well as any other program funded by MITI) cannot provide research funds to the university for such collaborative research; that is the function of a totally separate ministry within the Japanese government, the Ministry of Education, Science, and Culture (MESC). Most Japanese researchers believe that considerable friction exists between this ministry and MITI, although this may be a

well-orchestrated plan on the part of the government to provide parallel and competing paths for government seed money to university and industry research. MITI has little or nothing to do with university research. In the event that a university professor **does** get funding from MITI, MESC usually reduces that professor's budget by a corresponding amount. There are exceptions to the above; for example, in the so-called "Sunshine Project" MITI provides funds to five universities (Hiroshima, Kanazawa, Osaka, Tokyo, and the Tokyo Institute of Technology) for research on amorphous Si solar cells. Industry can and often does fund university research independently, often at the level of about 0.5 to 1.0 million yen, a very small program by U.S. standards ($2,000 to $4,000).

Although it is not the intention of this report to evaluate Japanese support of universities, a few additional remarks should be made. University research support through the MCE also tends to be in the form of "special project" programs, and the level of support for these projects is quite good. In 1985, total university funding by MCE was on the order of $175 million (i.e., ¥42 billion), $170 million of which was spent on so-called special projects. The 1985 figure is up 3.6 percent from 1984 (using yen rather than dollars for comparison). One of these projects is on mixed compounds of the III–V semiconductors and involves a large number of university researchers working in teams of from two to six faculty members on such subjects as AlGaSb ternaries, EXAFS of InGaAsP, GaAs/AlGaAs metal-organic MBE, and a focusing-type time-of-flight atom probe of these materials. To obtain this funding, a senior professor proposes the overall project or program, and many professors then work on it. One professor might get as much as $200,000 to $400,000 (maximum). There is also a standard increment of government support for university professors, but it is a very small amount (about $16,000 to $20,000), about half of which has to go to the university for facilities overhead.

It is this observer's opinion that, whereas cooperative research works extremely well between government and industry in Japan (far better than in the United States), it works badly between university and industry. For example, Japanese industry provides about twice as much support to **American** universities as it does to Japanese universities. A case in point is Matsushita, which is providing $1 million each to Stanford, Harvard, and MIT business schools to study U.S./Japanese relations. What little industrial research support is available tends to be directed to a relatively small number of senior faculty members, who nevertheless do excellent work under conditions that are far from ideal. Should the Japanese rectify this situation and take full advantage of the research talent and capability that exists within their educational system, the United States will really be in trouble!

The New Optoelectronics Effort

It now appears quite certain that there will be a new optoelectronics "project," to begin in 1987 after the termination of the present project. The current thinking for this project (as of mid-August 1986) is as follows, although these plans could still change appreciably before the plan is put into action.

- The project will probably last for 10 years, although the current budget under discussion is felt by many to be insufficient for 10 years.

- There will probably be a special laboratory, although it is not clear that the laboratory will have a 10-year lifetime. Current plans call for a laboratory of only 20 to 25 researchers, much smaller than OJL. Some of the equipment in OJL is currently being selected for transfer to this new project.

- There will probably be 13 members of that laboratory; in addition to the 9 members of OJL, 4 new companies are expected to participate: Fujikura Cable, Nippon Sheet Glass, Sanyo, and Sharp.

- The charter of the project will broaden to include InP as will as GaAs.

The organization of this new cooperative effort in optoelectronics is altogether different from the Optoelectronics Applied System Project, which has been described above. Funds for this cooperative activity originate from the privatization of Nippon Telephone and Telegraph (NTT), which had been wholly owned by the government. A fraction of the dividends paid by the new NTT stock will be used to finance research in a variety of fields; this is expected to amount to about $10 billion over the next 10 years. This money will be used to establish a new "association," which will involve two government ministries, MITI and the Ministry of Posts (MOP). The latter (MOP) will establish a science center in the Kansai area (Osaka, Nara, Kyoto), with participating members to include NTT, NKK, and other private companies. The former (MITI) will establish 10 or more new "companies," which will do research and development in such diverse areas as optoelectronics, synchrotron orbital radiation of lithography, optical measurement technology using the coherency of light, an electronic dictionary (related to the Fifth Generation Computer Project), etc. One of these "companies" is called the Optoelectronics Technology Research Corporation (OTRC) and is the "project" described at the beginning of this section. The 13 companies mentioned above joined OTRC in June 1986. Its budget is expected to be about ¥10 billion (about $60 million by the most recent exchange rate, summer 1986) for a 10-year period, 70 percent of which will come from the government association (i.e., NTT dividends) and 30 percent from the individual member companies. It is expected that there will be some sort of payback required to the government, possibly through patent royalties, although this is not altogether clear. As mentioned above, OTRC will have its own central cooperative research laboratory, possibly located in Tsukuba. In addition, each of the 13 member companies will have its own small laboratory working on optoelectronics.

The organization described above is complicated, and some aspects of it are still under discussion. It represents another bold, innovative approach to cooperative research, which takes maximum advantage of the change in status of one of Japan's greatest laboratories, NTT. However, the funds available for any one research subject supported by this program are not particularly large, and many Japanese managers are concerned that they are insufficient. For example, in the case of OTRC, the average annual budget will be of the order of $6 million, whereas the Optoelectronics Applied System Project described in this paper had a fiscal year 85 budget of nearly $15 million (see Table 3). Furthermore, the size of the joint cooperative laboratory will probably be less than half that of OJL (20 to 25 researchers instead of about 50 researchers in OJL). At the same time, most of the member companies have increased their commitments of resources to optoelectronics by a factor of approximately three since

the start of the project in 1979. Thus, the relative commitment to cooperative research in optoelectronics will be significantly smaller when OJL closes its doors.

SUMMARY AND RECOMMENDATIONS

This paper has described a very high level of basic research competence at a Japanese joint research laboratory, set in the context of a MITI-sponsored national cooperative research project. Nine private electronics companies and one government laboratory participate at OJL in a carefully chosen agenda of research topics of basic and generic materials problems that need to be solved if GaAs optoelectronic integrated circuits are to become an economic reality. Considerable (I'm tempted to say astonishing) progress has been made, both within OJL and within the individual laboratories of the member companies themselves. Particularly impressive have been OJL's advances in crystal growth (both bulk and epitaxial); advanced processing, such as maskless implantation and dry etching; the fabrication and processing of superlattice structures for novel device applications; and the characterization of defects in bulk, semi-insulating GaAs. In parallel with this, the member companies have carried out equally impressive research activities in their own laboratories on compound semiconductors and have moved the simpler GaAs devices into the market place, virtually dominating the III-V compound device market.

Although industry leaders seem to agree that the optoelectronics project has been a success, their reactions to MITI-sponsored cooperative research vary from unhappiness to guarded enthusiasm. Most would rather have their share of the funds under their own direct control, a not unexpected position! They favor the more fundamental and costly projects at OJL, since these would be more difficult to carry out in-house and involve little compromise of company-private information. Most companies have emphasized certain areas to support at OJL, and they are looking forward to the return of their research teams involved in those areas. For example, it has already been pointed out that Fujitsu will have a commanding lead in focused ion beam technology. Most managers with whom I spoke tended to minimize the extent of useful technology transfer that has taken place, although some specific examples have been described in this paper.

It does appear that participation in a cooperative laboratory has a very positive effect on newcomers to the technology. For example, Oki Electric has catapulted into the mainstream of III-V compound materials and devices during the short period of its participation in OJL. Another interesting example is Sumitomo's strong presence in Group 3 rather than Group 1, as noted above.

In both the VLSI and optoelectronics projects, joint cooperative research laboratories have functioned simultaneously and in parallel with a massive buildup within industry in the respective technology, and at the close of those laboratories Japan has commanded a position of technological and market leadership. In neither case can the cooperative research laboratory be the direct cause of that leadership, since it takes many years for research results to impact the marketplace, and the cooperative projects represented only a small percent of the resource commitments made. Nevertheless, these laboratories appear to play a very important twofold role: (1) the establishment, during the lifetime of the project, of a standard of research for the member companies that is

extremely synergistic; and (2) the establishment of a research base that will be all-important in maintaining that lead for many years to come. I believe that this is particularly true in the case of optoelectronics, where the Japanese have made a massive, long-range commitment to III-V compounds that far outstrips the effort made by industry in the United States and Europe. Not only is this commitment evident at OJL itself but at each of the basic research laboratories of the member companies. For example, the semiconductor research at Fujitsu is approximately one-third HEMT (GaAs), one-third optoelectronics (GaAs), and one-third Si (fine-line lithography, processing, etc.). In this regard, I think another comment written by Weinstein et al. (Ref 2) is particularly relevant:

> .....there is always the possibility that some new breakthrough could drastically alter the entire structure of the competition, much as the invention of the transistor affected companies dependent on the vacuum tube. For example, if the difficulties of working with gallium arsenide could be worked out and gallium arsenide came to be viewed as superior to silicon in optoelectronics and ultra-high-speed logic circuits, the Japanese lead in this revolutionary new technology could prove to be much more significant than the marginal increment to Japanese market share in RAMs about which so much concern is presently being expressed.

What should be our reaction to all of this? It seems to me that the Japanese have set a good example for us. Rather than withdraw into an isolated, competitive stance (which seems to be a fairly common tendency today, with strong overtones of unfair trade practices, etc.), I believe we should learn as much as we can from and about the Japanese. It is clear that much of their success has resulted from an ability to learn our technology and our culture, our language, our methodology of research, and its results. But, as is typical of the Japanese, when they absorb important elements of another culture, they transform it into something strictly Japanese, changing, transforming, and improving upon it. The cornerstones of Japanese success in "high technology" are communication and commitment, and I advocate more of the same in this country.

Communication

For communication, I think we should be sending our researchers, particularly the younger ones, to study and train in Japanese universities and research laboratories in increasing numbers. That process is already well underway; many programs are in effect or are in the planning stage (e.g., American Electronics Association, National Science Foundation) to send students, faculty, and other researchers to Japan, and they are being well received in an increasing number of laboratories. When one visits most industrial laboratories in Japan, one is struck by the number of mid-management people who have spent a significant period of time in the United States: 1 year at Cal Tech, 2 years at Berkeley, 3 years at Bell Laboratories, etc. In the past the flow has been primarily in one direction; it is important that a significant flow in the opposite direction be maintained. My invitation to OJL was the first of its kind; now a young French researcher has taken my place. For this communication to be optimum, a facility with the Japanese language is essential!

Exchange of visiting personnel is only the first step for adequate communication between our two countries. We must explore innovative ways to collaborate with Japanese researchers, either one-on-one or in an institutional sense. Would it be possible, for example, to structure some sort of joint laboratory or cooperative research program with both Japanese and American companies participating? At present that seems unthinkable, but much could be gained on both sides. We are not necessarily dealing with a zero-sum situation; instead, much could be done through imaginative collaboration to create new opportunities, new insights, new markets. Could a truly bi-national university be established in Tokyo or New York, Los Angeles or Osaka, with mixed student and faculty populations, and with research directed toward mutual problems? I believe that both countries will ultimately benefit from drawing closer to each other.

Commitment

The commitment of the Japanese electronics companies to long-range, fundamental research has been a recurring theme of this paper, particularly for research on III-V compounds. The dividends are obviously now being paid. The majority of III-V research in the United States is military, with relatively little basic research carried out in the industrial environment, except for a handful of the largest industrial laboratories. I believe we should spend far more money on GaAs electronic and optical devices and their integration to avoid the possibility of missing out on the next "transistor." This work needs to be expanded in our universities and in our indus..ial laboratories. In particular, university research laboratories are badly underequipped, yet they represent our strongest hope for the future. One of our unique strengths, relative to the Japanese, is the strong and growing interaction between the university and industry. Institutions such as the Semiconductor Research Corporation (SRC), the Microelectronics Center of North Carolina (MCNC), and the University of California MICRO program (matching state funds for university research funded by industry) should represent the tip of the iceberg; other approaches with significant additional funds are required.

ACKNOWLEDGMENTS

I first want to thank Dr. Izuo Hayashi, technical director of OJL, for arranging my visit to that laboratory and for his most gracious hospitality during my stay. Dr. Hayashi showed great sensitivity to my needs and concerns and spent many hours of his valuable time sharing with me his insights into the technical life of Japan.

I have also been encouraged and assisted by Dr. George Wright of the Office of Naval Research and Dr. Yoon Soo Park of the Air Force Office of Scientific Research (both of whom were stationed at the Far East Liaison Office in Tokyo), and by Dr. Robert Burmeister of Hewlett-Packard Laboratories, all of whom supplied me with information useful for this report.

Another person at OJL without whom I would have been totally lost was Mr. A. Okamura, who helped with countless problems involving every aspect of daily life in a totally strange country. His patience and good humor with what must have seemed an endless supply of needs and requests were greatly appreciated.

All of the other officers and managers of the laboratory were also most gracious hosts, particularly Dr. T. Iizuka, the director-general, who was attentive to my needs, enthusiastic about my research activities, and interested in my reactions. Dr. M. Hirano spent countless hours briefing me on collaborative research in Japan and handling administrative details that my presence created. Finally, all of the group leaders were generous with their time, eager to tell me of the activities of their groups, and interested in my well-being during my visit. All of the staff assisted me with enthusiasm with the many clerical, secretarial, and other needs that a visitor in a strange environment is constantly discovering.

Mr. Masami Tanaka was my MITI host; he arranged several important meetings for me and also contributed many of his own insights into government/industry cooperation. I also want to thank Mr. Kiyoshi Hasegawa, the Executive Director of the Engineering Research Association for the Optoelectronics Applied System Project, who helped make my visit possible.

Finally, each and every researcher in the laboratory treated me with kindness, friendliness, and respect. I feel that I have a new circle of close Japanese friends as a result of this experience.

FOOTNOTES AND REFERENCES

1. It is very difficult to make an exact comparison of market sales for the two countries, and therefore to determine when the curves for Japanese and U.S. sales actually cross (if they have already done so). Japanese market analysts believe that the figures reported for U.S. sales by most U.S. sources do not include so-called "captive" markets (devices produced for use within the company), and that the U.S. figures are therefore underestimates of the total U.S. market. In addition, accurate figures are hard to obtain because companies tend not to disclose this information. Some examples of the differences between U.S. and Japanese market estimates are given in Table 11. Japanese estimates for 1986 show the U.S. still ahead, whereas the U.S. estimates show Japan in the lead. Note that the Nomura Research Institute figures for 1985 Japanese sales ($8.2 billion) are 18 percent lower than the most recent MITI figures ($10.0 billion) which are given in Table 1. It should also be noted that one reason the Japanese can handle industry "slumps" better than the U.S. is the fact that the Japanese rate of capital investment is greater.

2. Competitive Edge, the Semiconductor Industry in the U.S. and Japan, Daniel I. Okimoto, Takuo Sugano, and Franklin B. Weinstein (editors). Stanford University Press, Stanford, California, 1984. Specific references in text are to pages 18–20, 38–39, and 69–70.

3. Japanese Electronics, A Worm's-Eye View of Its Evolution, Makoto Kikuchi. Translated by Simul International, Simul Press, Tokyo, Japan, 1983.

4. Triad Power, the Coming Shape of Global Competition, Kenichi Ohmae. The Free Press, a Division of Macmillan, Inc., New York, New York, 1985.

5. Japan's High Technology Race, The Information Technologies, John Sigurdson, Research Policy Institute, AV-Centralen Press, Lund, Sweden, 1983.

Table 11. WORLD SEMICONDUCTOR MARKET ESTIMATES

	SIA*	NRI†	
	1986	1985	1986
UNITED STATES	$9.2 B	$10.0 B	$11.5 B
JAPAN	9.5	8.2	9.4
OTHER**	6.7	6.6	7.3
TOTAL	25.4	24.8	28.2

* SIA is the Semiconductor Industry Association, an association of US companies.

† NRI is the Nomura Research Institute, a major survey company in Japan.

**Western Europe accounts for ≈80% of these figures.

6. Optoelectronic Industry and Technology in Japan, Optoelectronic Industry and Technology Development Association (OITDA), 20 Mori Building, 7-4, Nishi Shimbashi 2-chome, Minato-ku, Tokyo 105, Japan.

7. Both Mitsubishi and Sharp have announced the opening of facilities capable of producing one million lasers per month. However, Japanese planners believe that the sale of CDs will not be sufficient to sustain such a rate of production because the largest market for CDs is expected to be the automobile market, which should saturate at about 8 million cars per year. They are therefore eyeing the home computer market, for which a breakthrough in erasable CDs is required.

8. Note that in this and in all other tables in this paper, a currency exchange rate of Y240 per dollar has been used, a "best quesstimate" at a reasonably fair average over the lifetime of most of these projects. If today's exchange rate is used, the projects appear to be considerably more expensive.

9. "Fabrication Technology for Optoelectronic Integrated Circuits." T. Iizuka, T. Fukuda, H. Hashimoto, and K. Asakawa. Proceedings International Conference on Integrated Optics and Optical Communications (IOOC), Venice, Italy, October 1985.

10. "Evolution of Optoelectronic Integrated Circuit: OEIC," Izuo Hayashi. Proceedings International Conference on Integrated and Guided Wave Optics (IGWO), Atlanta, Georgia, February, 1986.

11. "Research Aiming for Future Optoelectronic Integration," Izuo Hayashi. Proceedings IEE, to be published.

12. It is not clear that InP-based materials should be totally excluded from consideration. Although the emphasis of OJL's activities has to do with OEIC rather than optical communications (and hence do not require the very low losses available in optical fibers at longer wavelength), InP may have advantages even for the short-haul systems envisioned for OEIC because of the zero dispersion characteristics of some fibers at these wavelengths, which would lead to higher bandwidth applications. In the final year of OJL some attention is being given to InP, as we shall see, and the next generation optoelectronics project will have more to do with InP.

A MEETING OF THE JAPANESE SHIP PERFORMANCE COMMITTEE

Justin H. McCarthy

For 2 days in late October I was privileged to be one of two non-Japanese people to attend a meeting of the Japanese Ship Performance Committee (JSPC) of the Society of Naval Architects of Japan (JSNA). The other special attendee was Dr. Neil Bose of the University of Glasgow, who is currently working as a Research Fellow at the Ship Research Institute in Tokyo. My sponsors for the meeting were Professor Hisashi Kajitani of Tokyo University and the Chairman of JSPC, Professor Hajime Takahashi of Tokyo Mercantile Marine University. The meeting, one of three programmed each year by JSPC, was held at the Kobe Works of Kawasaki Heavy Industries and attended by 60 leading Japanese researchers in the field of ship hydrodynamics. JSPC meetings are informal forums at which ongoing research is presented and miscellaneous topics of mutual interest are discussed. In the latter category, considerable time was spent discussing reports and preparations for the 18th International Towing Tank Conference to be held at Kobe in October 1987.

The JSPC is actually one of two JSNA committees devoted to marine hydrodynamics. It is concerned with ship flow and resistance, both viscous and wavemaking components, and propulsor hydrodynamics, including cavitation and propeller-induced vibration. The other committee is concerned with ship maneuvering, ship motions in waves, and the dynamics of offshore structures. The purpose of these committees is to inform colleagues in the Japanese hydrodynamics community of new developments some months prior to formal publication of results, to allow authors to receive constructive criticism and to promote cooperation between researchers throughout the country. As in the JSNA as a whole, the committees draw about 60 percent of their members from the universities, with the remainder about equally divided between government institutes and private industry. To be eligible for committee membership, one must author or coauthor three papers in the committees' fields of inquiry. Committee members are drawn from not only JSNA, which is a national professional society for the marine field, but also from two regional societies: the Kansai Society of Naval Architects, covering the Osaka region, and the West Japan Society of Naval Architects, covering western Honshu and Kyushu. I was impressed by the wide spectrum of ages represented at the JSPC meeting, from young Ph Ds to emeritus professors, and by the obvious long-time comradery that has existed between members.

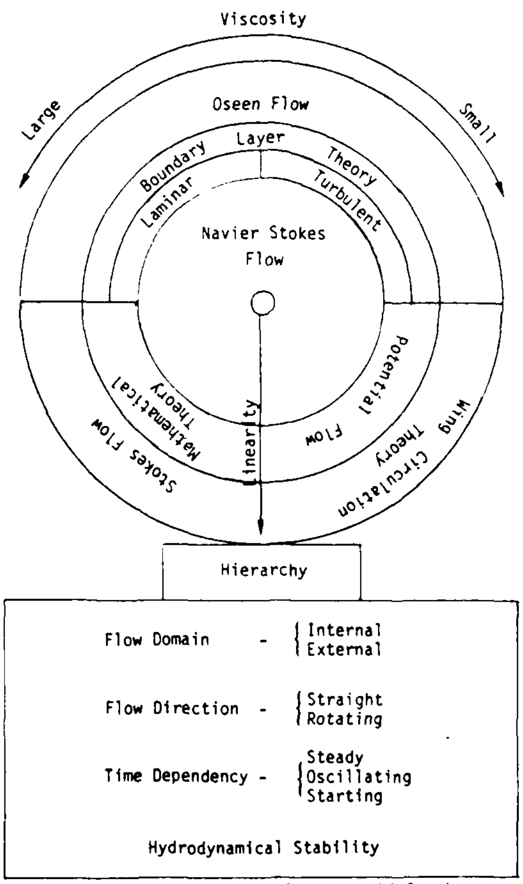
While there are very serious concerns about the future of shipbuilding in Japan, it was clear that despite the halving of both worldwide and Japanese shipbuilding tonnage since 1975, following the Mideast oil crisis of 1973, the Japanese ship research community has continued to thrive right up to the present time.

Nine "papers" were given at the JSPC meeting, covering a broad collection of topics including the new ice towing tank at the Nagasaki Research and Development Center of Mitsubishi Heavy Industries, experimental data obtained by the Japan Marine Science and Technology Center in Yokosuka on noise associated with the formation of cavitation bubbles, a novel ship propeller

arrangement investigated at the Nippon Steel Corporation (NKK) to increase propeller efficiency and reduce fuel costs, and a survey of deterministic theories of turbulence presented by Professor Masatoshi Bessho of the National Defense Academy. In some cases hand-written versions of the papers were distributed; in other cases the papers were entirely oral. Extended and lively discussions followed all of the papers, whose authors and titles are listed in the Appendix. In the following, I very briefly call attention to aspects of only the latter two papers which, together with the other seven papers, should be published within the next 12 months.

The paper by Professor Bessho contained a unique and compact mandala of theories of incompressible fluid flow. The mandala, shown below, will be immediately clear to workers in the field of fluid mechanics. Mandala is a Sanskrit word that originally meant circle, group, or collection. It is a symmetrically arranged symbolic diagram used in Hinduism and esoteric Buddhism to express fundamental religious doctrine for the purposes of ritual and meditation and can provide a path to enlightenment. The conceptual connection of religion to fluid mechanics should not be alien to students of turbulent flow in particular!

MANDALA OF
THEORY OF INCOMPRESSIBLE FLUID



Reprint courtesy of Prof. Masatoshi Bessho,
National Defense Academy, Yokosuka, Japan.

Perhaps the most complete investigation presented at the meeting was reported in the paper by Dr. Matsumoto of NKK. Laboratory model experiments have been completed for a novel configuration in which the propeller on single screw ships is angled off to the port or starboard side of the longitudinal centerplane of the ship. The hull's boundary layer vorticity naturally provides an off-center net swirling flow into the propeller that can be used to null the counterswirl produced downstream of the propeller, resulting in lower kinetic energy losses and about a 6-percent higher propulsive efficiency than the conventional centerplane propeller configuration. Because of hull flow symmetry, there is no net swirl upstream of a propeller located on the centerplane. While swirl cancellation is not a fundamentally new concept, Matsumoto is the first person to report full evaluation experiments covering propulsion, cavitation, vibration, maneuvering, and stopping performance for this particular type of configuration. From a hardware standpoint, the concept offers a simpler approach to ship fuel savings, when compared to other types of energy-saving configurations currently being used on ships. These other configurations include stationary swirl-inducing vanes upstream or downstream of the propeller, flow smoothing ducts or nozzles upstream of the propeller, and downstream vane wheels. Future full-scale evaluations of the NKK off-center propeller would be very welcome, but unfortunately they are not currently scheduled.

Appendix

JAPANESE SHIP PERFORMANCE COMMITTEE PRESENTATIONS

21 October:

"Introduction to the New Ice Towing Tank"
Katsuyoshi Takesumi (presented by Kayo)
Nagasaki R&D Center, Mitsubishi Heavy Industries

"Icebreaking Power of Icebreakers and Structures in Ice"
Kazuo Nozawa
Kobe Works, Kawasaki Heavy Industries

"Examination of Resistance Increase of Rough, Wavy Surfaces"
Yoji Himeno
Department of Naval Architecture, Osaka Prefecture University

"Bubbles and the Cavitation Generation Mechanism"
Shinichi Takagawa
Japan Marine Science and Technology Center, Yokosuka

22 October:

"The Effect of a Change of Stern Configuration on Powering Performance"
Norihiro Matsumoto
Nippon Steel Corporation

"Survey of Deterministic Theories of Turbulence"
Masatoshi Bessho
Department of Mechanical Engineering, National Defense Academy

"Numerical Simulation of Viscous Flow Around Ships"
Yoshiaki Kodama and Takanori Hino
Ship Research Institute, Tokyo

"Finite Difference Simulation of Free-Surface Flow Around a Wigley Model Using Body-Fitted Coordinates"
Takanori Hino
Ship Research Institute, Tokyo

"Numerical Simulation of Wave Breaking"
Hideaki Miyata
Department of Naval Architecture, University of Tokyo

REVIEW OF WORKSHOP
ON
DESIGN, ANALYSIS, AND RELIABILITY PREDICTION FOR CERAMICS

PART I

Edward Mark Lenoe

SUMMARY

This workshop was held at the International House of Japan in Tokyo on 18 and 19 September. There were 100 attendees consisting of 81 Japanese, 8 Americans, 2 Canadians, and 9 Europeans. The meeting was well conducted and featured simultaneous translation, which greatly facilitated verbal exchange in the workshop atmosphere. Twenty-five papers, including 13 by Japanese authors, were presented, and the workshop concluded with a Reporterial Session. The meeting was partially supported by the Office of Naval Research and hosted by the Japan Fine Ceramics Center. The workshop was organized by an international committee composed of eminent academicians and government and industrial experts. The committee was headed by Dr. Shinroku Saito and Professor Hiroaki Yanagida of Tokyo University.

Because of the length of the review, as well as other priorities, it is split into two parts. In Part I, the first two sessions are discussed and some of the pertinent questions and answers and the statements of the reporterial activity are presented. During the workshop, much useful technical information was communicated. It is believed that a significant portion of the dialogue that occurred between authors and participants will prove of interest to specialists in the areas discussed, and so that dialogue is included in the following pages.

Workshop chairmen were: Dr. Osami Kamigaito, Toyota Central Research Laboratories; Dr. John Mason, Garrett, U.S.A.; and Dr. Yoshiteru Hamano, Kyocera Corp., Japan. Welcome greetings were extended by Dr. Masatoshi Morita, President, Japan Fine Ceramics Center, and introductory remarks were made by Professor Hiroaki Yanagida, Tokyo University. Dr. Shinroku Saito closed the workshop with summary remarks. Of special interest were his statements that the Prime Minister's Office has decided to adopt Japan's materials projects as strategic technology in future industries, and that the major thrust of the heat engine work that has been managed by the Research Association of Fine Ceramics, under Ministry of International Trade and Industry (MITI) sponsorship, will now be supporting development of power generation via gas turbines! For more than 5 years now, emphasis of the Japanese heat engine programs has been on vehicular type engines. But because of the reduction in fuel oil taxes, which contribute to the special-purpose funds that have provided support for the heat engine projects, the direction of work will shift. The target for the electric power field is a 10,000-kW coal gas turbine. These multiyear studies will be conducted with government support at about ¥10 billion per year. During November, a special industrial and government group from the Engineering Research Association, basically the group that has monitored the heat engine projects, will be conducting their annual international assessment of the technology base to aid them in program management of the Japanese efforts and in deciding on specific tasks of the long-term projects.

Regarding this workshop, the presentations demonstrated the substantial progress that has been made by ceramics producers in improving yield and reliability of components. This is shown by substantial increases in strength and burst speeds achieved in various turbocharger rotors. It is interesting that the most progress seems to have been made by Japanese suppliers.

As of last fall, quite a number of leading United States ceramics experts believed that the U.S maintained a substantial lead over the rest of the international community, particularly in the areas of design and analysis and understanding of fracture mechanics and fracture mechanisms. Information presented by Japanese experts at the workshop should effectively dispel that notion. In this regard, the turbocharger work reported by Nissan and its suppliers, as well as the high level and quality of university research discussed herein, is of special interest. Also of interest are the substantial efforts underway in Japan on tensile and other mechanical testing and the associated round-robin evaluations being conducted not only in strength characterization but in fracture behavior.

Of particular interest were three papers dealing with some of the unique applications of structural ceramics, i.e., large blower fans, large heat exchangers, and applications of ceramics to air-sliding mechanisms. Regarding blower fan applications, several examples were provided of 17.5- to 25-percent improvements in fan efficiencies and annual energy cost savings of ¥30 to ¥40 million, respectively. Perhaps these applications can be viewed as some "fruits" of research and development (R&D) efforts. The workshop also clearly indicated that while in the United States and perhaps in some European countries the development of advanced ceramics technology is mainly supported by the government, in Japan it is mainly the industries that provide financial support. Perhaps this helps explain the steady increase in commercial applications of ceramics in Japan.

SESSION I. DESIGN AND ANALYSIS

AGENDA

Speakers from leading automotive, engine, and ceramics industries participated as follows:

1. Hiroshi Matsuoka, Isuzu Motors Ltd., Research Center, "Development Status of Isuzu Ceramic Engines"

2. Takane Itoh and T. Watanabe, Nissan Motor Co., Ltd., Engineering Laboratories, "Application, Design, and Analysis of Gas Turbine and Turbocharger"

3. Toshihiro Yamada, A. Kohno, K. Yokoi, and S. Hioki, Hitachi Ltd., Mechanical Engineering Research Laboratory, "Joining of Ceramics by Active Metals"

4. Mark Lasker and John Mason, The Garrett Corporation Headquarters and Airesearch Industrial Division, "Garrett Experience with Turbochargers"

5. Edward Lenoe, Office of Naval Research, Liaison Office Far East, "Review of Ceramics Design and Analysis Procedures"

COMMENTS

Matsuoka

The first speaker described the development status of the Isuzu ceramic engine. Hiroshi Matsuoka reported that development of the Isuzu engine has progressed to such an extent that the ceramic engines are superior to common water-cooled engines in performance under certain operating conditions. He stated that Isuzu ceramic engines have undergone various tests for at least 3,000 hours with no problems experienced. Test vehicles fitted with this engine and without radiator cooling systems can operate continuously at 130 km/h. The ceramic engine has survived more than 100,000 miles of testing, with power output and fuel economy about 30 percent higher than the conventional engine. Figure 1 shows the construction of the Isuzu ceramic engine.

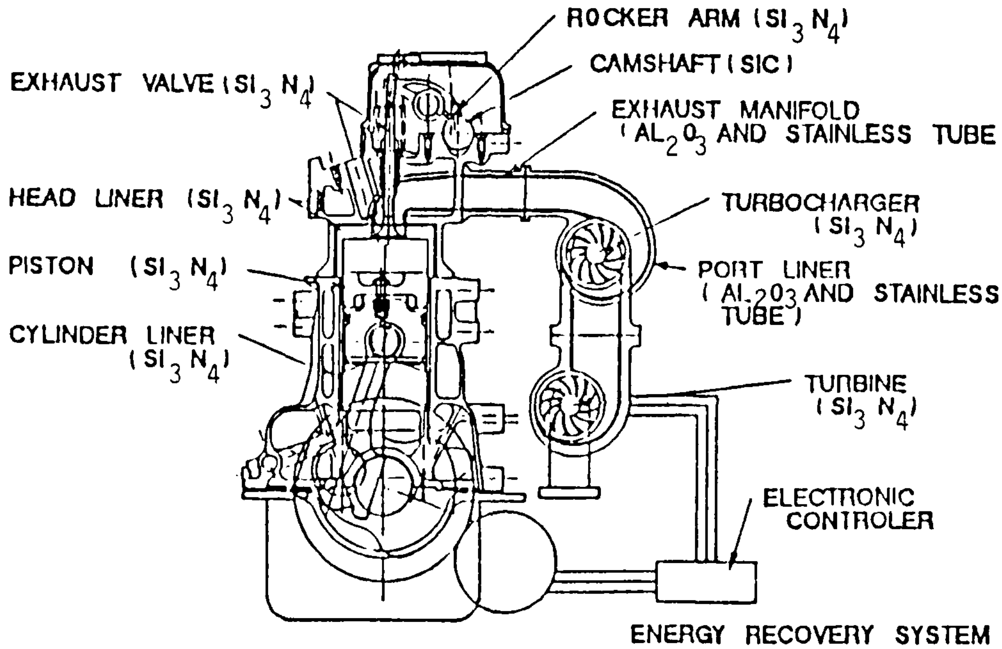


Figure 1. Construction on Isuzu ceramic engine.

The engine uses monolithic ceramics for the fire deck of the cylinder head, the cylinder liner, the piston head, intake and exhaust valves, and turbocharger rotors. To handle hot exhaust gases, ceramics and ceramic coating materials are used for exhaust ports, exhaust manifolds, and turbine scrolls. During testing, Isuzu used many kinds of ceramic materials, including silicon nitride, silicon carbide, partially stabilized zirconia, alumina, and numerous types of coatings.

Based on tradeoffs and experience considering high temperature strength, toughness, and thermal shock resistance, silicon nitride ceramics are receiving the greatest attention. Their applications generally have maximum temperatures in excess of 800 °C.

It is interesting that Isuzu has mass produced its ceramic hot plug in the swirl chamber of a small diesel engine since 1983. A key consideration in application of ceramics is the joining of dissimilar materials. In this paper, an interesting example of a joining technique was discussed. Figure 2 shows the construction of the Isuzu adiabatic piston, wherein a metal ring is fitted into the groove around the ceramic shaft and then heated by a high frequency coil to a flowing state while the ring is pressed and cooled to form a high quality ceramic-metal joint. The claim is that the joint strength is several times higher than conventional diffusion bonds or solid-liquid phase bonds. Figure 3 is a schematic showing the ceramic-metal joining method.

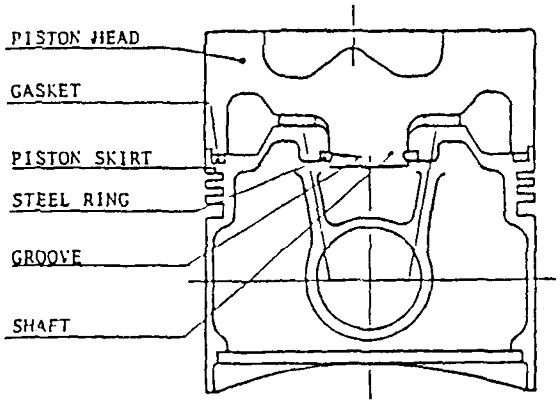


Figure 2. Construction of an adiabatic piston using a new joining method.

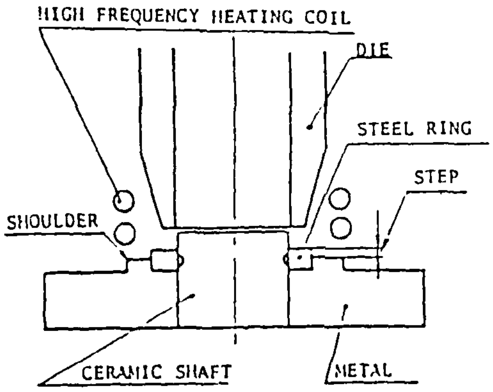


Figure 3. Schematic showing the ceramic-metal joining method.

In his presentation, Matsuoka emphasized the importance of accurate calculation of both thermal and mechanical stresses. For instance, in determining an acceptable hot plug geometry, a combined analytical and experimental method was required. Hundreds of different ceramic hot plugs underwent experimental evaluation. Figure 4 shows the general construction of the ceramic hot plug. Figure 5 shows the fairly wide range in temperature differences that results by using three different geometries. Furthermore, Matsuoka emphasized that the optimized design could only be achieved if it were coupled with adequate quality control and good production processes. All in all, it appears that Isuzu is aggressively committed to the use of ceramics in its engines.

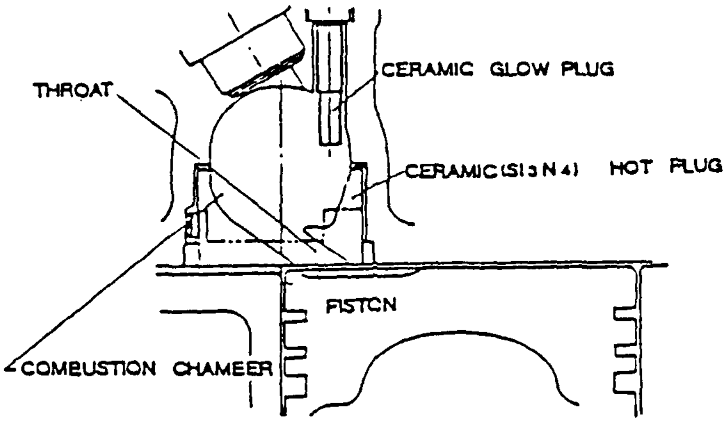


Figure 4. Construction of ceramic hot plug.

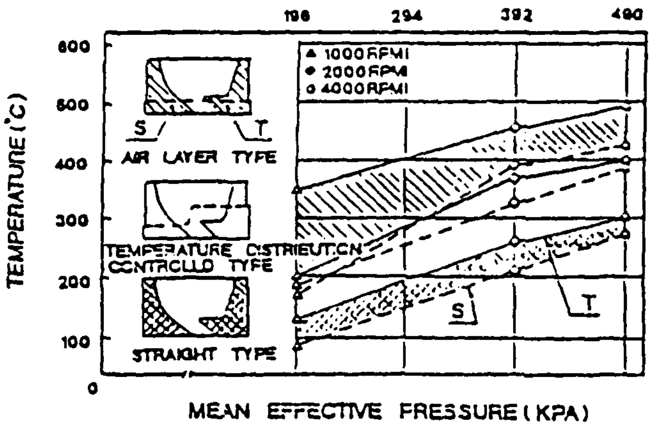


Figure 5. Measurement of temperature difference in three different hot plugs.

Question:

How do you solve lubrication problems and the wear of lubrication materials when these engines are actually in operation?

Answer:

In the liner, the top part of the liner and the bottom part of the liner are separated. The top is connected with the lower surface of the cylinder head, and this part becomes extremely hot. However, the bottom part of the liner does not have this basic adiabatic structure because of its very low temperature. The piston also has a very hot top part but a very much cooler lower part. When the piston moves, the low temperature liner area and the low temperature skirt area of the piston are moving simultaneously; thus, we can use normal oil for this engine.

Question:

How much fuel does the adiabatic diesel engine save?

Answer:

This engine, at a partial load of about 1,000 rpm, saves more fuel than the direct water-cooled conventional engine. However, because the inlet temperature deteriorates at a high rpm, we still have not tested how much the fuel economy will be in that case.

Question:

What about the exhaust gases and the NOX content, since with increased temperature you might increase NOX, which can cause serious problems. Do you think the NOX content and level of exhaust gases will increase with increased temperature?

Answer:

We have not looked at hydrocarbon, nitrous oxide, or other exhaust contaminants because we are now working on fuel economy with respect to the conventional engine. The next stage in our research will be improving the NOX and HC levels. We think there will be a 10- or 20-percent improvement in the exhaust.

Question:

You did carry out a temperature calculation. I believe the heat loss from the piston and cylinder was about the same. You said the upper and lower parts are separated, but the heat loss seemed to be comparable. How did you calculate the heat loss for these areas?

Answer:

We calculated the heat loss for both the top and bottom separately. Actually, in the top, when we measured the top and bottom part of the liner, we found that they were comparable.

Itoh and Watanabe

In the second paper, authors Itoh and Watanabe discussed Nissan Motor Company activities on turbochargers. Even though these turbochargers are small (about 100 mm in diameter), such work, of course, has implications for gas turbine applications. They described efforts with three types of materials: sintered silicon carbide (SSC), conventional sintered silicon nitride (SSN), and gas pressure sintered silicon nitride (GP–SSN). As reported in their studies, these materials had average flexural strength properties ranging from 490 to well over 870 MPa, respectively. It is interesting that the first conventional metal turbocharger for a passenger car in Japan was introduced into the Nissan Cedric in 1979. Supposedly, this was due to a growing demand for improvement in performance, specifically in so–called turbo lag. Therefore, Nissan's efforts have been aimed at improving the boost response by using lighter materials, focusing on the development of ceramic radial turbine rotors. Turbochargers with GP–SSN ceramic rotors have been successfully introduced into the Nissan Fairlady Z (October 1985) and into the Nissan Skyline (May 1986). Application of ceramics to the turbine rotor lowered the moment of inertia of the rotor assembly by 34 percent compared to a conventional metal rotor. Original marketing plans projected sales of about 400 to 500 ceramic turbochargers per month for the Fairlady Z. No doubt much valuable field experience has been gained.

The authors described the design, stress analysis, reliability, and durability of ceramic radial turbine rotors. They reported that reliability of the ceramic turbocharger rotor was improved significantly by development of a GP–SSN material in a new rotor molding method, a new brazing method, and three–dimensional stress analysis for substantially reduced peak stresses. Regarding rotor fabrication for sintered silicon carbide, the blade section of the rotor was formed via injection molding and the hub section by cold isostatic pressing (CIP); the two sections were joined by CIP into a monolithic part, which was then sintered. Basic data for estimating burst speed of the rotors were obtained by sectioning selected rotors, according to the schematic shown in Figure 6. Three–point bending tests were performed on 4– by 8–mm bars with 20–mm spans. Based on these results, along with weakest link Weibull theory, the rotor burst strengths were estimated. Rotors were subjected to both hot and cold spin test conditions, and failure analysis was conducted.

The probable causes of failures for rotors that burst at lower than anticipated speeds were discussed. It was found that the builtup or integrated shaft is very sensitive to slight deviations from the design configuration. Incoming foreign particles also initiated failures. Thickness of the rotor blade tips was an important parameter, and increasing blade thickness had a notable effect in improving the impact resistance to foreign particle damage. Based on the experimental observations, it was concluded that today's silicon carbide was not feasible for the ceramic turbocharger.

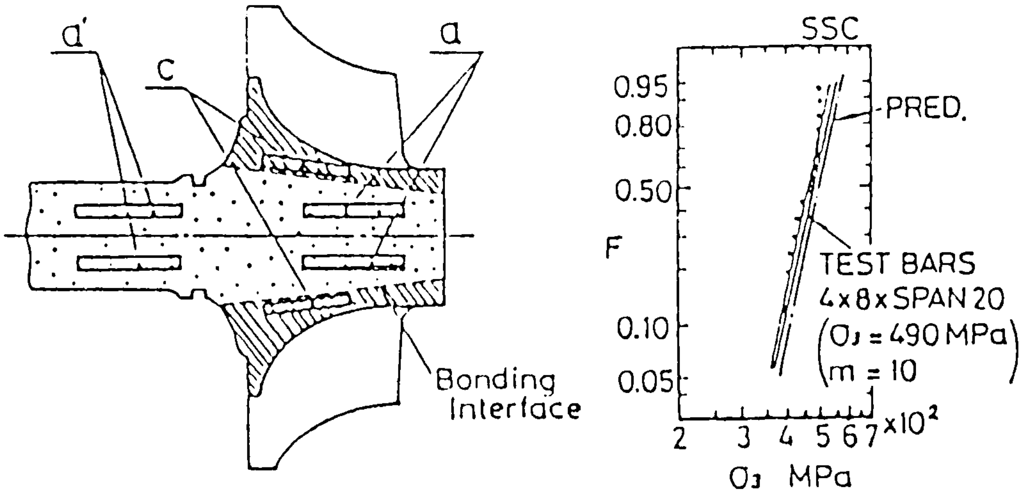


Figure 6. The Weibull plot of test bars cut from type 2 rotor.

Comparative strength data were obtained for the SSC, SSN, and GP-SSN, and the results are shown in Figure 7. As previously described, the blade and hub sections were formed separately and flexural strength measurements were made. Results of such tests are listed in Table 1, which shows fairly uniform mean strength results for the different regions of the rotors.

Efforts were made to confirm the reliability of the ceramic rotors. Hot spin rotor tests were completed at steady state rpm corresponding to maximum applied peak stress of 263 MPa and for instantaneous burst testing. Figure 8a illustrates disagreement between the hot spin tests to failure and the estimated strength results. Mean strength of the rotors was observed to be 317 MPa, or about 77 percent of the predicted strengths. Figure 8b illustrates the steady state rotor results in terms of time to failure. Based on these data, it is suggested that about 1 percent of the rotor cannot survive more than 10,000 hours at the design conditions.

It was decided that no acceptable, inexpensive proof test method could be readily applied, and therefore full-scale proof testing was carried out. Subsequent to such screening, steady state fatigue tests were completed on a number of rotors and the data appear in Figure 8c. Compared in the graph are failed rotors that were not proof tested along with 10 rotors that were. None of the proof tested parts failed. In addition, a ceramic turbine rotor was installed in an engine for endurance testing. This consisted of more than 15,000 hours of endurance tests including 1,000 hours of high speed testing, heat soak back, and cyclic endurance testing. Based on these tests, the GP-SSN ceramic rotor was deemed to be sufficiently reliable for actual use.

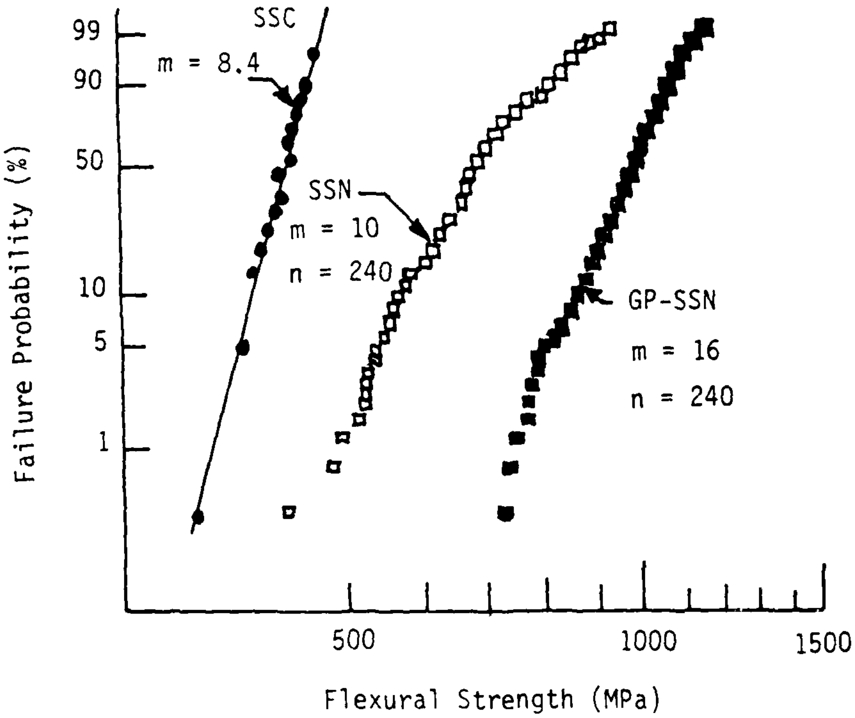
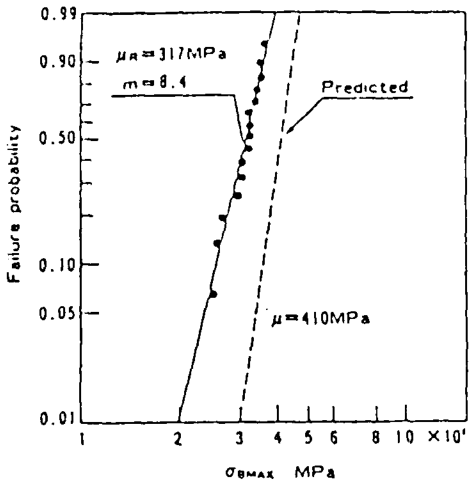


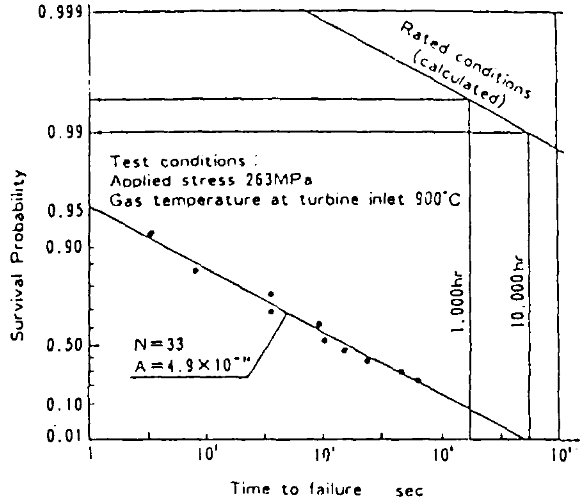
Figure 7. Comparative strength data.

Table 1. Strength of Rotor Parts

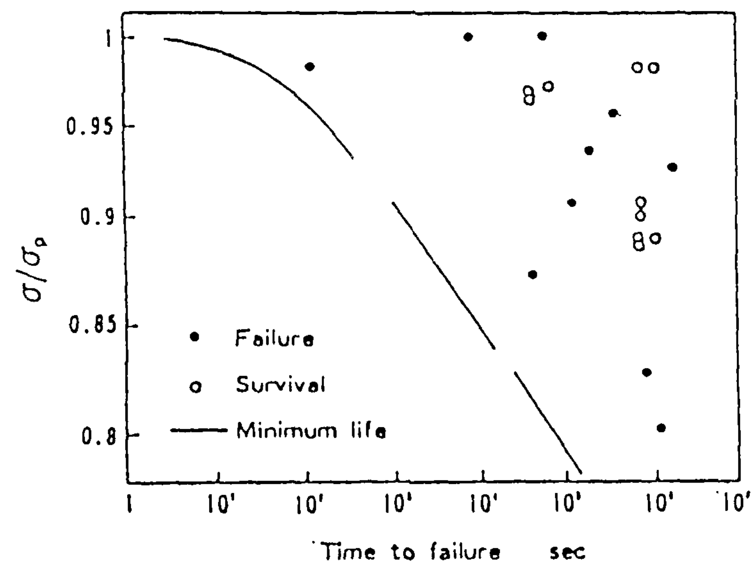
Part Measured	Relative Density (%)	Flexural Strength (MPa)
Blade	99.5	890
Shaft	99.2	860
Joining Area	--	870



(a) Actual rotor strength versus predicted.



(b) Time to failure for rotors.



(c) Fatigue life after proof testing.

Figure 8. Fatigue behavior of rotors.

Question (Tokyo University):

Although proof testing is very useful, it appears that in reality fatigue strength has not been improved. Why?

Answer:

In our proof tests, our aim was not so much to reduce the portion of scattering but rather to minimize it to obtain estimates of the minimum life. We assume the minimum life can be calculated from the constants A and n. After the proof tests, if the result is below the estimated value, then it would be a real problem. The important thing here is every point exceeds the minimum life. Our results would be acceptable if we could control the quality so that all points fall between the minimum and maximum life. Our research has not progressed beyond these areas yet.

Question:

How did you measure the constants A and n?.

Answer:

The horizontal axis is time and the vertical axis is the survival probability. We apply constant speed conditions on a certain rotor. In this case, applied stress is 263 MPa. With this speed we keep the rotor running; some rotors break earlier than others. We fit a straight line, using Weibull theory, and assume crack propagation according to a power law, then we can estimate A and n from the rotor data.

Comment:

You have only a short time for some rotors. Maybe if the time is short, then the situation would be different (different short versus long time failure mechanisms!). Maybe it should not be a straight line; maybe the line should be curved.

Answer:

Maybe a portion of the curve can be applied, but with constants A and n obtained from the experiments, we would like to confirm that the rotors do not break within the rated conditions. That means we can set the minimum life and we can prove that the rotors do not break within the minimum life.

Comment:

In the case of turbine design, a designer would want to make the blade thinner, as thin as possible.

Answer:

We are very much interested in that point also. In the case of the gas turbine rotor, how the designer achieves that within all the system requirements is a very critical question.

Yamada

The third paper was presented by T. Yamada. This was an in-depth presentation of studies of joining of ceramics by active metals. The method involved diffusion bonding of ceramics with alloy sheets of aluminum and Fe-Ni as interlayers. Thicknesses of these aluminum and Fe-Ni alloy sheets were 0.6 and 0.8 mm, respectively. Two types of each metal, namely pure aluminum and Al-10 Si, and Fe-Ni-Cr and Fe-Ni-Co alloys were used. Ceramics tested were pressureless sintered silicon nitride, silicon carbide, sialon, alumina, and zirconia. Metals investigated were Cr-Mo steel, 29 Ni-17 Co steel (Kovar), and tungsten carbide alloy (WC-6 Co). Obviously, these materials encompass a wide range of mechanical, physical, and chemical properties.

To evaluate bond strength, specimens 10 mm in diameter and 25 mm in length were diffusion bonded at temperatures ranging from 500 to 1,200 ^{o}C, at pressures from 0.5 to 5 kg/mm^2 for 30 minutes in a vacuum chamber of 10^{-4} Torr and in Ar. Optimum bond conditions were determined by means of four-point bending tests. Under these conditions, it was found that contact pressure hardly influenced the joint strength since it appeared independent of ceramics or metals tested. Highest joint strengths were obtained for temperatures between 590 and 610 ^{o}C, in which case only the Al-10 Si alloy layer was in a molten state. On the other hand, lowest strength levels were associated with use of pure aluminum, or application of process temperatures that exceeded the melting point of pure aluminum. It was observed that the strength of the joint decreased with an increase of thermal expansion difference between ceramics and metals. The type of ceramic and metal had direct influence on the strength of the joint. Some of the effects of processing parameters and materials properties are shown in Figures 9 and 10.

Yamada also stated that the strength increased with an increase in interface width, and I believe this means the thickness of the bond region. Residual stress measurements after bonding indicated that reduction of residual strength is associated with increases of strength. The matter of increasing the bond thickness apparently reduced the residual stresses. A note of caution is appropriate concerning the use of the term "strength." These experiments were conducted on small specimens that were tested in flexure and the results interpreted in a strength of materials or rather simplified way. Defining the absolute strength of a joint in such a way that the results are universal is no easy task. Be that as it may, the maximum strength of joints was obtained for combinations of 29 Ni-17 Co steel, tungsten carbide, and aluminum alloy. Maximum strengths for the optimum combinations were found to be as follows:

Material	Strength (kg/mm^2)
Sialon	32
Silicon Carbide	15
Silicon Nitride	22
Alumina	20

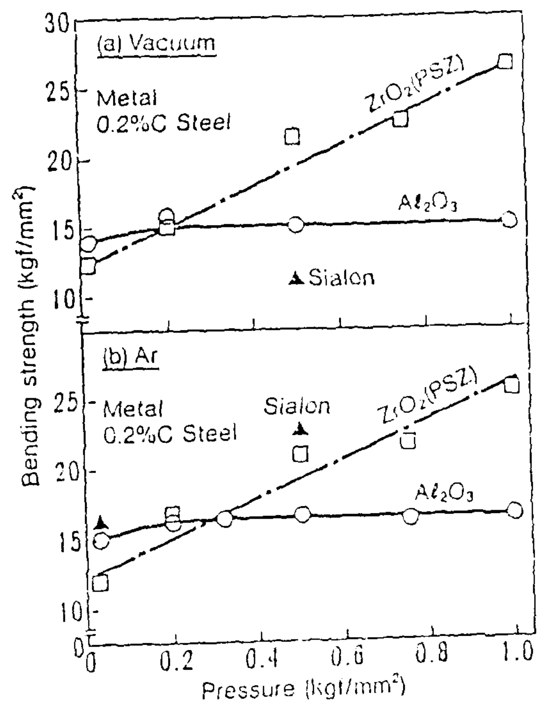


Figure 9. Effect of pressure and atmosphere on bending strength.

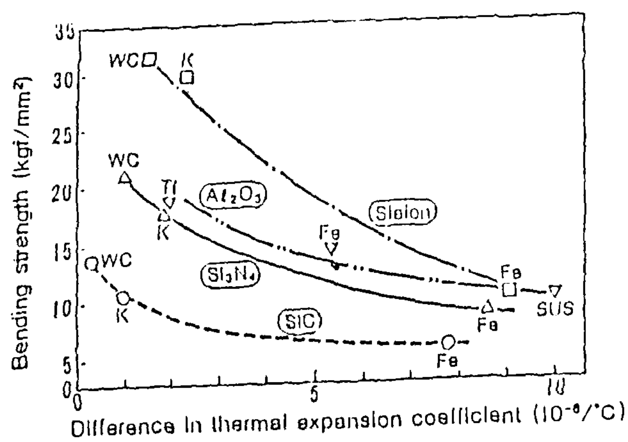


Figure 10. Bending strength of specimens joined with Al-Si filler plotted as a function of the difference in the thermal expansion coefficient.

In general, the "hot" bend strength did not change below 300 ^{o}C but dropped rapidly above 350 ^{o}C. The strength of the Fe-Ni alloy interlayer was generally lower, at about 17 kg/mm^2, compared with the Al-Si interlayer. While the joint was weaker, the Fe-Ni alloy did not degrade at temperatures lower than 700 ^{o}C. Scanning electron microscope observations were conducted and showed that aluminum carbide (Al_4C_3) reaction products were formed at the ceramic interface and intermetallic compounds were found at the metal interface (Fe_2Al_5, $FeAl_3$). It was concluded that Al-10 Si alloy was a promising interface material because it formed a transient liquid phase that increased the diffusivity and promoted reactions and enhanced intimate contact. Yamada concluded his presentation with slides of ceramic turbochargers fabricated of silicon nitride, sialon rotors attached to metal shafts, and small alumina oxide heat exchangers requiring hermetic sealing to aluminum.

Question:

How similar are the aluminum silicon alloys that you mentioned to the alloys that are used in brazing aluminum parts? These are also aluminum silicon alloys.

Answer:

I think they are almost the same.

Question:

You talked about the relationship between bending stress and fracture toughness. What is the specimen used for examining fracture toughness?

Answer:

In the case of sialon, I used the Vicker's microhardness indenter technique. But we have not really confirmed the fracture toughness for other materials. We just used catalogue values from manufacturers' information.

Mason

In the fourth paper of this session, Dr. John Mason described the ceramics applications being pursued by Garrett-Signal Corporation in general but specifically concentrated on the turbocharger application. He concluded by saying that when ceramic component costs drop to where they are about 20 to 25 percent higher than metals, then they perhaps become economically feasible.

Garrett Automotive recently completed a multiyear activity to develop and produce several ceramic turbocharger configurations. These turbochargers ranged from the T2 passenger car turbocharger (48-mm tip diameter) to the T4 (74-mm tip diameter) for diesel applications. Silicon nitride was chosen for the application. Mason reported that acceptance of ceramic turbochargers has been mixed and most European and North American vehicle manufacturers have been unwilling to pay a premium for such components. He stated that based on future production rates of the order of a million ceramic turbochargers a year, one can

compute that about 400 tons of metal turbine wheel alloy would be replaced by about 150 tons of silicon nitride, or other ceramic. This quantity is not large enough to bring about a major cost reduction effort from raw materials or component suppliers. On the other hand, in Japan, Nissan has been willing to make the necessary expenditures to exploit the advantages of introducing turbochargers.

Since 1983, Garrett has been testing ceramic turbochargers in test stands and in passenger cars. The early vehicle tests proved the benefits of ceramic turbochargers in terms of improved engine transient boost response and vehicle acceleration. Foreign object damage was established as a prominent failure mode. Turbocharger endurance testing in vehicles and in test stands at temperatures up to 750 °C and tip speeds up to 400 m/s showed the need for significantly improved strength and fracture toughness for 1983 vintage materials. Regarding materials improvements, Figure 11 indicates the burst speed improvements resulting from improved materials in 1983, 1984, and 1985. Dr. Mason reported that vehicle testing has involved more than a dozen passenger cars, the majority of which are gasoline. As of September 1986, total ceramic turbocharger running time in vehicles exceeded 11,000 hours and distances exceeded 425,000 miles. Most encouragingly, failures of the types encountered in early experiments were virtually eliminated.

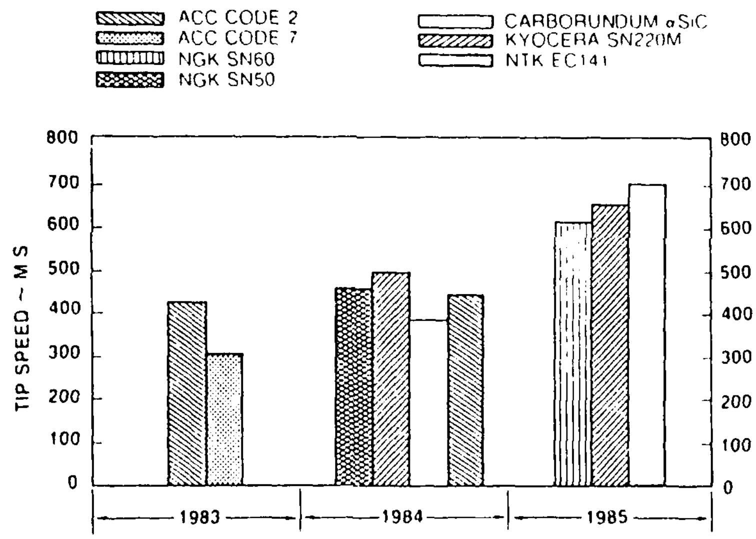


Figure 11. Burst speed improvement verifies material strength improvements and consistency.

Question:

Isn't improved acceleration the driving force for this whole push toward ceramic turbochargers?

Answer:

Better acceleration is really a measure of what we call driveability. It isn't the only measure of whether when you step on the accelerator something happens. But it really is one positive index that all of us to one degree or another appreciate. And the perception of automobile companies worldwide is that better acceleration performance is a factor not just for racing cars but for street cars and not just for sports cars but for cars that are driven by the general public. Now whether that will lead to ceramic turbochargers getting into all cars that are turbocharged is a very good question.

Question:

What is the bearing system that is running hotter than a normal one?

Answer:

Going to ceramics gives the turbocharger a capability of coping with a higher temperature than would be feasible with a metal. With the higher engine exhaust temperature comes secondary problems of lubrication and possible overheat of the engine oil, not just during normal operation but after shutdown. It turns out that the most critical situation with regard to engine oil overheat is not during engine operation when you have a flow of oil through the bearings from the engine but after shutdown when the so-called soak back will tend to heat up the bearing area of the turbocharger and will oxidize the oil in the bearing. That's the problem. And you've raised a good question to the extent that the ceramic turbocharger might permit a higher operating condition. How do you cope with that in bearing design? There are a couple of ways. One way that is done to some extent in production (it's a little bit messy, but it works) is to use a water-cooled center housing of the turbocharger. That eliminates the problem. Experimentally we're looking at air bearings that use no oil and can cope with the turbocharger.

Question:

You showed a top temperature of around 1,150 °C. Is there any pressure, any design pressure, to increase that temperature?

Answer:

I think that is pretty much a top temperature, within rated power. Design practice in gasoline engines varies and so does what you might call the load factor, the degree to which the engines are run at or near their rated conditions. The perception is that European engines of small displacement, on the autobahns, tend to run long times at high engine speed and high engine power and they tend to challenge the maximum temperature capability of metal. A temperature of 1,150 °C is on the high side of what we are going to see. A very challenging temperature level for turbochargers would be 1,000 to 1,100 °C, and 1,150 °C, which was on one of my slides, is an extreme condition. I don't think it will go higher than that.

Lenoe

The last paper in this session was a short presentation by Lenoe. The speaker briefly touched on a wide range of subjects. He attempted to discuss the major programs that have been conducted in the United States and Europe, highlighting significant achievements. Some aspects of uncertainties in design and analysis as well as test rigs were discussed. This provided some insight into the interdisciplinary modeling and analysis techniques as well as experimental requirements for typical heat engine applications. He tried to stress that currently the major area of uncertainty is assumed to be solely in materials properties, but other pertinent factors of ignorance must also be taken into account in generalized probabilistic design and analysis. Lenoe made an appeal to state or report not only survival or lifetime probabilities but also the associated confidence intervals in full-scale sensitivity types of analysis and design. In this way efforts could be concentrated on appropriate technology barriers and costly premature failure might more readily be avoided.

Question:

In general, you have provided a good overall review of the U.S. heat engine programs but not in the area of nondestructive evaluation (NDE) in the U.S. Could you comment on that?

Answer:

It would take quite a while to talk of NDE programs, especially since there is not a single unified central program but rather a wide range of research across the country. In addition to innumerable small-scale research efforts, there are several large-scale programs. One recent example is the Center for NDT, which just began at the University of Iowa. As I said, there is a lot of activity in this area in the United States.

Comment:

May I make a small comment, say on cooperative research, particularly those areas of NDT and wear research. I think these are areas where there is not so much competition involved between companies. Perhaps this is an area suitable for cooperation between the U.S., Japan, and Europe. For instance, there is no simple wear test at high temperature. There is no simple way to measure the wear behavior between two ceramics. In the European community we are trying to develop new test procedures/new measurement systems for measuring wear in ceramics. Of course there are some organizations like the International Organization for Standardization (ISO) where they make new standards. But it sometimes takes 20 years to make new standards. There is also an activity called VAMAS where such cooperative efforts are already underway.

Answer:

There are actually many round-robin tests, bilateral and multilateral.

Comment:

In Canada we have a coordinated NDE program, a continuing, multiyear program funded by our Defense Department, and it will go foı 6 years! The program is at McMasters University.

CHAIRMEN SUMMARY COMMENTS

Dr. Kamigaito

In Session I, some systematic studies to realize performance in engines were presented. It was shown that ceramics can be used successfully as reciprocating engine components giving higher performance to the engine if these components, such as piston heads, cylinder heads, cylinder liners, valves, turbochargers, etc., are designed reasonably. Furthermore, if the design is reasonable, we can get sufficient heat insulation, which makes the reduction of various cooling systems in the engine possible. Also, it makes the application of conventional oil to such a conventional heat engine possible in spite of its high temperature combustion. For the design of ceramic components, finite element methods were proven to be very useful. On some aspects we have much knowledge, but on other aspects we have many problems to be resolved. For example, we need to understand the high temperature behavior of structural ceramic materials, and high strength material having high temperature durability in the range up to 1,350 °C must be developed. For this application, coating and composite technology development of ceramic materials should be studied, especially base ceramic materials such as silicon nitride, silicon carbide, mullite, zirconia, etc. As ceramics are very sensitive to surface and inner flaws, so material properties are dependent on the size of the component. Thus, it is important that we make clear the relationship between size of the component and material properties. Without this, we cannot optimize.

Dr. Mason

On the Isuzu paper by Mr. Matsuoka on the ceramic diesel, it was very interesting to see the success that has been achieved with a wide variety of components even though there was no attempt to hide the fact that there are plenty of problems and plenty of more work needs to be done. This paper, although it was primarily devoted to ceramics, is very interesting to people in the engine business who are wondering about the future of the adiabatic diesel.

Moving on to the Nissan paper by Mr. Itoh, the subject was gas turbine and turbochargers, but as we all know, 80 to 90 percent of the discussion was devoted to the ceramic turbocharger technology of both Nissan and their supplier company, which was reported in a later paper. Nissan deserves considerable credit for having actually made a commercial entry into the field of structural ceramics. For this type of product, it is a first. I have one question: Is the two piece construction that was reported for the turbocharger necessary? It works; maybe it is the best way to go, but I am not sure. I thought the paper was very knowledgeable in its discussion of such things as integrity in event of failure.

Regarding the next paper on the joining of ceramics by active metals by Mr. Yamada, I was impressed by the variety of ceramics, metals, and interface materials that were considered: five ceramics, three metals, and two interface

materials. Although the application was largely joining of ceramics to metals with relatively low temperature braze type materials, clearly the technology developed and discussed will be of great interest for people who are trying to develop methods of joining ceramics with higher temperature materials. Dr. Wurm mentioned joining as the kind of research that's going on in Europe. The U.S. Government is considering that kind of research in the United States and I certainly hope they build on this excellent work.

Commenting for a moment on my own paper, I tried to stress the importance of ceramics, and by the way the Nissan paper and the Garrett paper seemed to have the same objectives or the same rationale for the case of ceramics. In my paper there was considerable discussion of erosion damage where the short term action, clean up the exhaust, was emphasized. The longer term action might well be to try to develop ceramics that will live in an adverse environment. There was a brief discussion of economics. The premise was made, "ceramics are here, the future depends on getting the cost down."

Dr. Ed Lenoe in his paper gave a most interesting summary of the ceramics-oriented research and development work in the heat engine that has been going on in the last 12 to 15 years. He mentioned the early Ford-Westinghouse-Garrett programs as well as the more recent advanced gas turbine programs by the Garrett-Ford team and by Allison. He also touched on the work at Daimler Benz and United Turbine in Europe.

You can say that small gas turbine performance requirements, beyond ceramics, are very demanding. You have to get the leakage down. If we had ceramics totally worked out, I think there would still be a question as to whether the ceramic gas turbine would immediately find a home in passenger cars, although as a gas turbine proponent I would say the gas turbine has an excellent future. Clearly from an applications standpoint, we are confidently expecting to use ceramics in heat engines in the next 10 years, even though there's a lot of work that needs to be done.

SESSION II. THEOLOGICAL BEHAVIOR OF CERAMICS

AGENDA

Speakers from centers of excellence discussed fracture mechanics, time-dependent behavior, friction and wear, environmental effects, and general failure mechanisms as follows:

1. Masahiko Shimada, Applied Chemistry, Faculty of Engineering, Tohoku University, "Corrosion of Nonoxide Ceramics"

2. Edwin R. Fuller, Jr., Institute for Materials Science and Engineering, National Bureau of Standards, "High Temperature Structural Reliability of Ceramics: Creep Damage Regime"

3. Albert S. Kobayashi, R.C. Bradt, and A.F. Emery, University of Washington, Seattle, "Static and Dynamic Fracture Toughness of Structural Ceramics"

4. Minoru Kawai, H. Fujita, H. Takahashi, H. Abe, and J. Nakayama, Asahi Glass Co., Ltd., R&D Division, "Fatigue and Life Time of Ceramics at Elevated Temperature"

5. Ronald H. Baney, Dow Corning, Midland, Michigan, "Ceramic Matrix Composites: Some Promises and Problems"

COMMENTS

Shimada

Professor Shimada of Tohoku University presented an interesting summary of his investigations of structural ceramic instability under oxidizing atmospheres. In particular, he reported on a series of corrosion tests carried out to evaluate the oxidation resistance of SiC, Si_3N_4, and AlN ceramics in various alkali sulfate and alkali carbonate melts. These ceramics were reacted with the different melts exposed to air and nitrogen gas atmospheres at temperatures ranging from 700 to 1,200 °C. Microstructural changes, stoichiometry, and kinetics of the different reactions were investigated. Professor Shimada proposed possible reactions and models for the observed corrosion phenomena. For his experimental studies, sintered SiC with B and C additives, sintered Si_3N_4 with Y_2O_3 and Al_2O_3, as well as hot pressed AlN without additives were prepared as 4- by 5- by 8-mm rectangular bars. Typically a weighed specimen along with alkali carbonate or sulfate powder was placed in a high purity alumina tube, 16 mm in diameter and 170 mm in length. The tube was then placed in an electric furnace at the desired environmental conditions. When the corrosion tests were carried out in a nitrogen atmosphere, nitrogen gas was injected at the rate of 20 ml/min. Following exposure for the desired time and temperature, the tube was removed from the furnace and quickly cooled. The specimens were washed with hot water, dried, and cooled to room temperature. Then the crystalline phases and surface microstructures of the oxidized samples were subjected to x-ray diffraction analysis and scanning electron microscopy.

While various oxidation reactions of SiC, Si_3N_4, and AlN are possible, Shimada suggested that the following reactions are most probable:

$$4\ SiC + 3\ K_2SO_4 = 4\ SiO_2 + 4\ CO + 3\ K_2S \tag{1}$$

$$2\ SiC + 3\ K_2CO_3 = 2\ SiO_2 + 6\ K + 5\ CO \tag{2}$$

$$2\ Si_3N_4 + 3\ K_2SO_4 = 6\ SiO_2 + 4\ N_2 + 3\ K_2S \tag{3}$$

$$Si_3N_4 + 3\ K_2CO_3 = 3\ SiO_2 + 2\ N_2 + 6\ K \tag{4}$$

$$8\ AlN + 3\ K_2SO_4 = 4\ Al_2O_3 + 3\ K_2S + 4\ N_2 \tag{5}$$

$$4\ AlN + 3\ K_2CO_3 = 2\ Al_2O_3 + 6\ K + 3\ CO + 2\ N_2 \tag{6}$$

Next let us consider the high temperature results. In this instance AlN, SiC, and Si_3N_4 specimens were immersed in melts of K_2SO_4 and K_2CO_3 while exposed to air at 1,013 and 1,200 °C. Results from these

tests are shown in Figure 12. Note especially the excellent resistance of AlN to potassium melts, the large weight loss of Si_3N_4 in both types of salts, and that SiC dissolved rapidly in the K_2SO_4 melt but was fairly resistant to the K_2CO_3 melt.

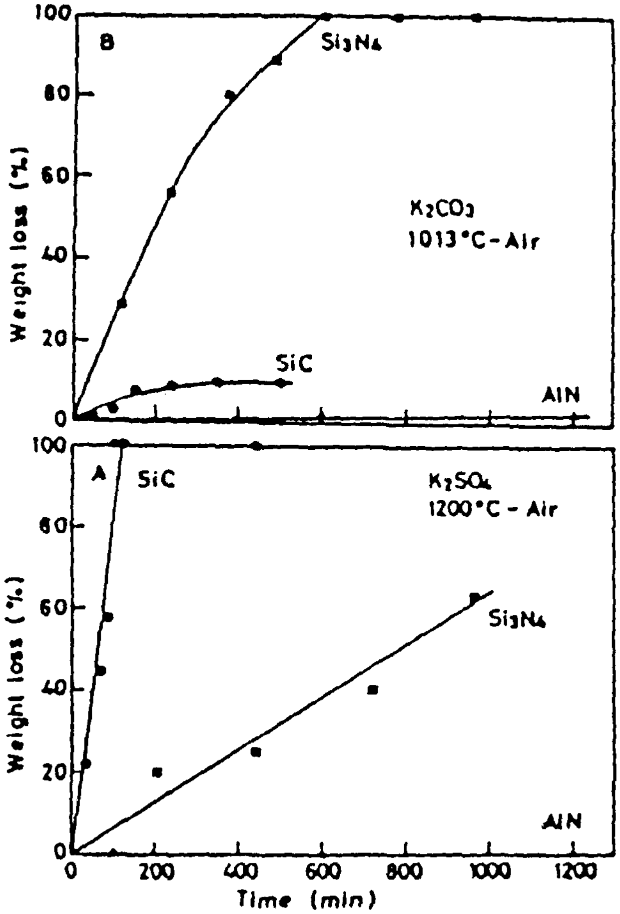


Figure 12. Time dependence of the weight loss of SiC, Si_3N_4, and AlN.

Surface examination under the scanning electron microscope revealed the following phenomena. Evolved gases led to extensive roughening of the surface with bubble formations. With Si_3N_4 immersed in K_2SO_4 melt, a film of about 50 microns was formed. Similar microstructures were observed in the AlN. In the ~~nitride and~~ carbide, x-ray diffraction peaks attributed only to SiC and Si_3N_4 were observed on the surface. ~~On the other hand, on the AlN~~-oxidized surface, AlON and alpha Al_2O_3 were detected. The results indicated that a film of these materials formed on the surface and controlled the oxidation rate in the AlN in the potassium salt melts.

Additional experiments were conducted wherein SiC and Si_3N_4 samples were exposed to K_2SO_4 and K_2CO_3 melts in nitrogen gas for up to 20 hours where the molar ratios of salt were varied from 0.5 to 5.0. The reactions in some of these systems seemed to proceed quantitatively; for instance, the weight loss of SiC in K_2SO_4 as well as that of Si_3N_4 in both salts increased linearly with increasing molar ratio. Based on observations, the reactions indicated in Equations 7 and 8 seemed likely. On the other hand, SiC in the K_2CO_3 melt showed only limited weight loss. Shimada postulated that weight loss in the SiC might be caused by the oxidation of SiC to SiO_2 owing to the dissolved oxygen and by the dissolution of SiO_2 into the K_2CO_3 according to Equations 10 and 11.

$$16\ SiC + 13\ Si_3N_4 = 4(K_2O \bullet 4SiO_2) + 16\ CO + 5\ K_2S + 4\ K_2S_2 \quad (7)$$

$$16\ Si_3N_4 + 27\ K_2SO_4 = 12(K_2O \bullet 4SiO_2) + 32\ N_2 + 3\ K_2S + 12\ K_2S_2 \quad (8)$$

$$81\ K_2CO_3 + 24\ Si_3N_4 = 18(K_2O \bullet 4SiO_2) + 36\ N_2 + 81\ CO + 63\ K \quad (9)$$

$$2\ SiC + 3\ O_2 = 2\ SiO_2 + 2\ CO \quad (10)$$

$$4\ SiO_2 + K_2CO_3 = K_2O \bullet 4SiO_2 + CO_2 \quad (11)$$

Weight loss of the Si_3N_4 immersed at 1,000 to 1,200 °C in potassium sulfate is shown in Figure 13, where it can be seen that above the melting point of the salt the rate of weight loss increased significantly. In Figure 14, Arrhenius plots for corrosion rate constants are presented for various molten alkali sulfates and carbonates. The apparent activation energies for the corrosion of Si_3N_4 were 430 kJ/mol and 106 kJ/mol for sulfates and carbonate melts, respectively.

Question:

When the gas turbine is exposed to salt, several problems can exist. What can be done to prevent this?

Answer:

Our research has just begun in this area. We need to make models to determine the reaction between sulfates and nonoxide ceramics and to prevent corrosion. For example, tetragonal zirconia has an unstable surface, and by aging at a low temperature and in the presence of water vapor, a reaction between the water vapor and the surface of the zirconia ceramics could take place. So I'd like to extend our work to make models and determine which method is the best to prevent the reaction.

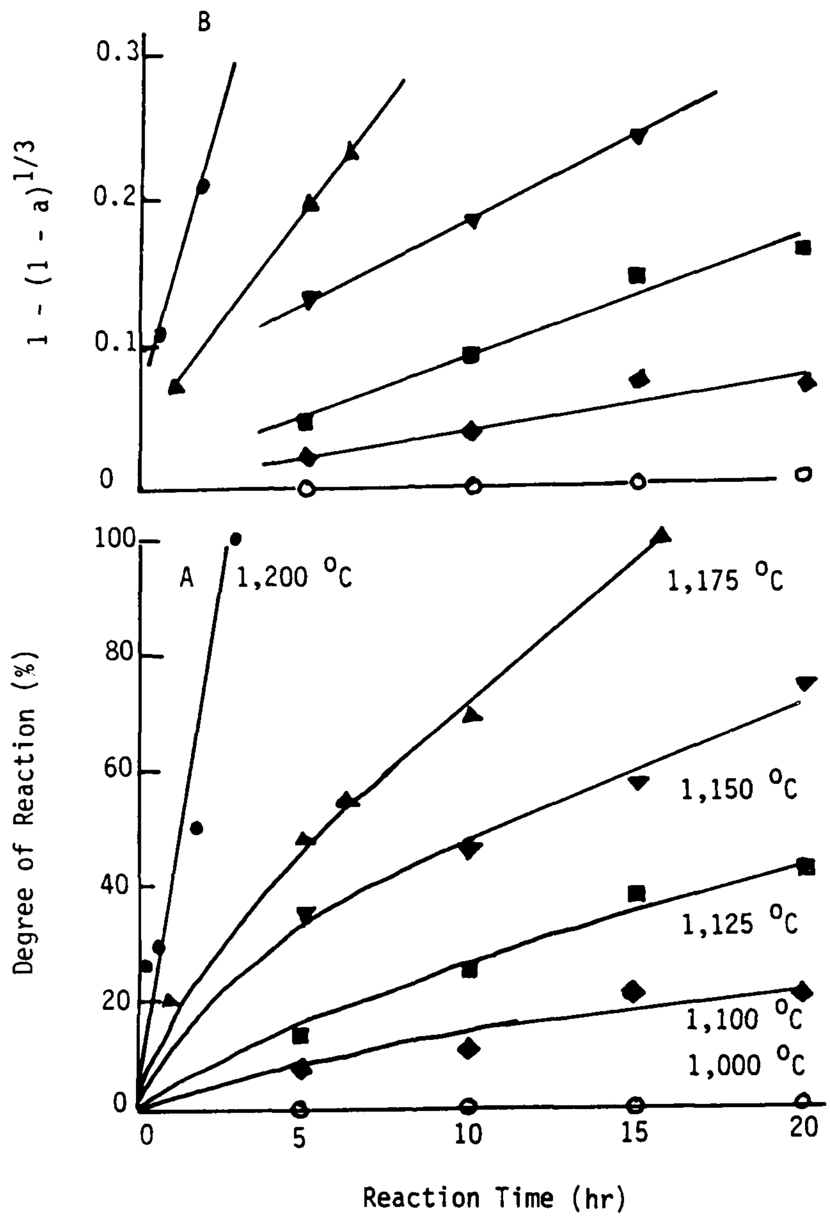


Figure 13. Time dependence of the weight loss of Si_3N_4 in K_2SO_4 melt.

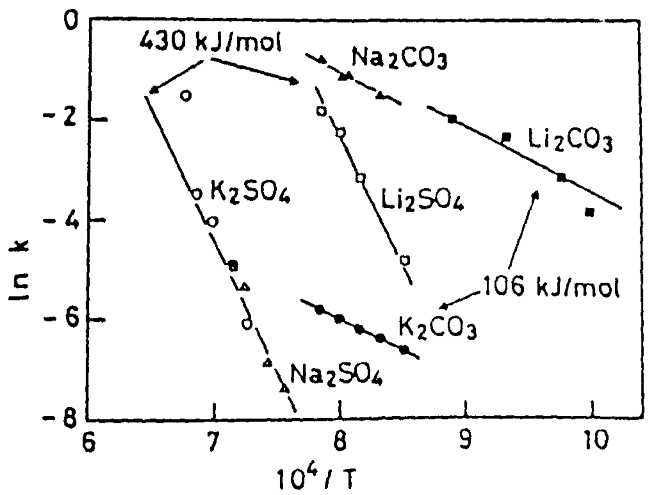


Figure 14. Arrhenius plots of the corrosion rate constants.

Question:

I think it would be of great interest not only to work with sulfates and carbonates but also with chlorides since salt is spread on roads in Europe and America. So would that make a difference? Could you also do some experiments in that area?

Answer:

No, not yet, just only carbonates and sulfates.

Comment:

P&W of Canada is going to introduce a silicon nitride blade into one of its engines. P&W is very nervous about flying this airplane near the sea because of the salt and the sulfates in the exhaust. We should really look at ways of stopping corrosion by chlorides, sodium chlorides especially.

Question:

You used pressureless sintered silicon nitride with alumina and magnesia sintered additives. What was the amount of additives and what about the reaction of the additives with the salts in the corrosion tests?

Answer:

The total amount of alumina and magnesia is 10 percent by weight. These additives are almost entirely located as glassy phases at the grain boundary of silicon nitride. That is why I've extended our research work to changing the

Question:

Please discuss the n values for different temperatures.

Answer:

For this rupture test the n value is about 31 with the stressing rate test. With much faster cycles there is a difference in n, but for the fine-grained materials there is a coincidence of values for the other data.

Question:

What is the practical value of having n so large? Is there any practical significance of n being 300 or larger? It seems to me like it's almost instantaneous failure from a realistic standpoint.

Answer:

Well you are right, but it's only an experimental value, about 300 or over. The silicon carbide that we are manufacturing must be tested because we want to see what the characteristic values of our material will be so we can relay that information to our customers.

Comment:

But you have to understand that for n over 20 the lives are practically insignificant. It seems like in the fracture mechanics community I see many large values of n reported, but I think it does not have much practical significance. It's not just your work; I am addressing the literature in general.

Comment:

We are finding silicon carbide materials, particularly those materials that are more or less resistant to slow crack growth. Remember that this whole terminology and the whole thing came over from our experience in glass and glass ceramics. But when you are developing materials that are inherently resistant to slow crack growth in some instances, in fact you get strengthening after exposure! We really have to rethink some of these things. I think as shown by Dr. Fuller, the damage mechanism is quite different in these inherently resistant materials. In fact, we do not know how to treat them analytically. So these numbers are perhaps meaningful in that they are giving us the opportunity to rethink the whole formulation. We can no longer, in the inherently crack resistant materials, go forward with our old assumptions.

Fuller

Dr. Fuller reviewed current methods for assessing the high temperature structural reliability of ceramics based on fracture mechanics. Next he described his extensive studies of flaw initiation and flaw growth in a variety of ceramic materials. Recent data on generation and accumulation of creep damage at elevated temperature and the need for incorporating these data into a reliability assessment were discussed.

Question:

The origin of these microcracks is quite intriguing. There seems to be a preferential direction to the origin and contiguous propagation. From these pictures it is not evident, but is it between the interface between the silicon and silicon carbide or the interface between the reaction-bonded silicon carbide and the other silicon carbide? The Hexaloy KT material has alpha SiC grains that have been siliconized. That means you have more or less four phases: silicon phase, reaction-bonded beta phase, alpha phase, and unreacted carbon or graphite phase. What happens to the beta material, the cubic crystal versus the hexagonal, in terms of microcrack formation? Could you speculate on that?

Answer:

In terms of what we have seen, we tend to find clusters of what appear to be SiC grains. Occasionally you will find cavities; these are areas that initiate early on but appear not to link at all—they almost appear to be benign. The other cavities appear to occur between SiC grains in the silicon phase and to nucleate rapidly. Either you see them or you don't. They span between the two SiC facets, and when they nucleate they grow rapidly to a critical size that limits them to the interface spacing between them. Therefore, it would be nice to investigate other materials and look at various spacings and compositions. The phenomenon has to do with the constraint of the material that's creeping, and at some point the material can't go any farther. In most of the silicon nitride materials you have a glassy phase, so the critical parameters in terms of the microstructure are the thickness of the glass film and how much of each phase you have. Although it won't carry over one-to-one, I think there will be some very similar things that will happen in all of the high temperature ceramics.

Question:

From your talk, I would expect that there would be an activation energy spectrum, where one region would be stress dependent and the other region may or may not be strain dependent. How do you look at those things?

Answer:

From analyzing the alumina data, there appear to be two regimes.

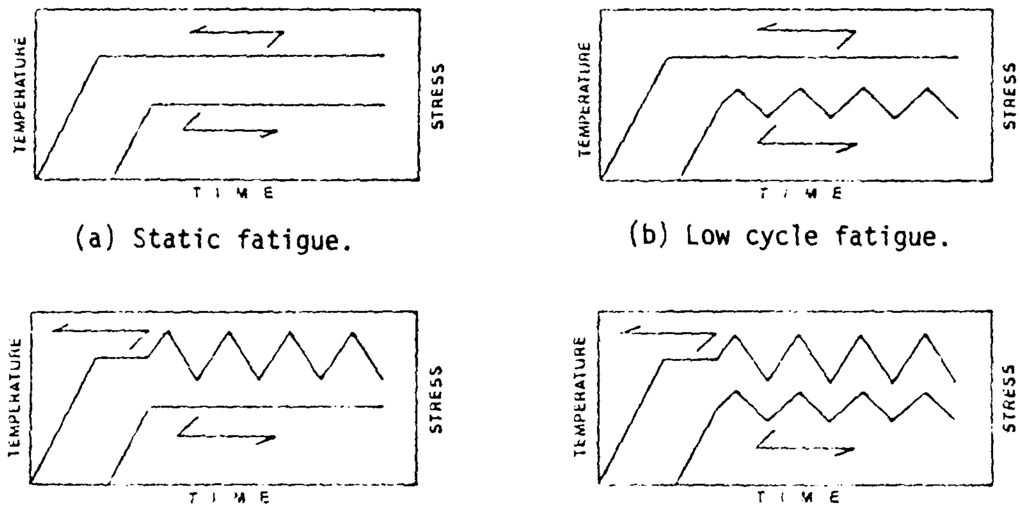
Kobayashi

Professor Kobayashi discussed static and dynamic fracture behavior of several types of ceramics. In particular, his study was concerned with fracture processes that control fracture. To begin, a linear crack closure force versus crack opening displacement (COD) was postulated for the fracture process zone. This fracture process zone, together with a totally elastic unloading process, was used to attempt to replicate subcritical crack growth in an unnotched ceramic composite beam under monotonic and cyclic displacement loadings as shown in the Figures 16 and 17.

grain boundary phase. The second step is to treat a crystalline phase at the grain boundary, for example alumina and yttria, and then hipped silicon nitride without additive. I'd like to compare these data for the glassy phase and crystalline phase and without additives.

Kawai

The next paper was given by Dr. Kawai, who described extensive tensile testing on sintered silicon carbide up to temperatures of 1,400 °C and silicon nitrides up to temperatures of 1,200 °C in air for up to 2,000 hours. The fatigue testing was conducted under the four conditions illustrated in Figure 15, namely static fatigue, low cycle fatigue, static fatigue under cyclic temperature change, and thermal fatigue with cyclic changes of synchronized temperature and stress. In all, test failure was controlled only by slow crack growth.



(a) Static fatigue.

(b) Low cycle fatigue.

(c) Static fatigue with cyclic temperature change.

(d) Synchronized cyclic change of stress and temperature.

Figure 15. Patterns of stress and temperature adopted in fatigue tests.

Under static fatigue conditions at temperatures below 1,200 °C, no fatigue was observed in sintered SiC containing alumina, while at temperatures over 1,300 °C slow crack growth fatigue was observed. It was observed that survival stress limit decreased with temperature, corresponding with a decrease in K_{IC}. On the other hand, sintered silicon nitride exhibited slow crack growth starting about 1,000 °C and also had some fracture patterns relating to different stages of static fatigue. Finally, in all fatigue tests under cyclic stress change, cyclic temperature change, and synchronized change of temperature, fatigue characteristics seemed to be controlled only by the accumulation of slow crack growth. No definite acceleration due to cyclic change of either stress or temperature was observed.

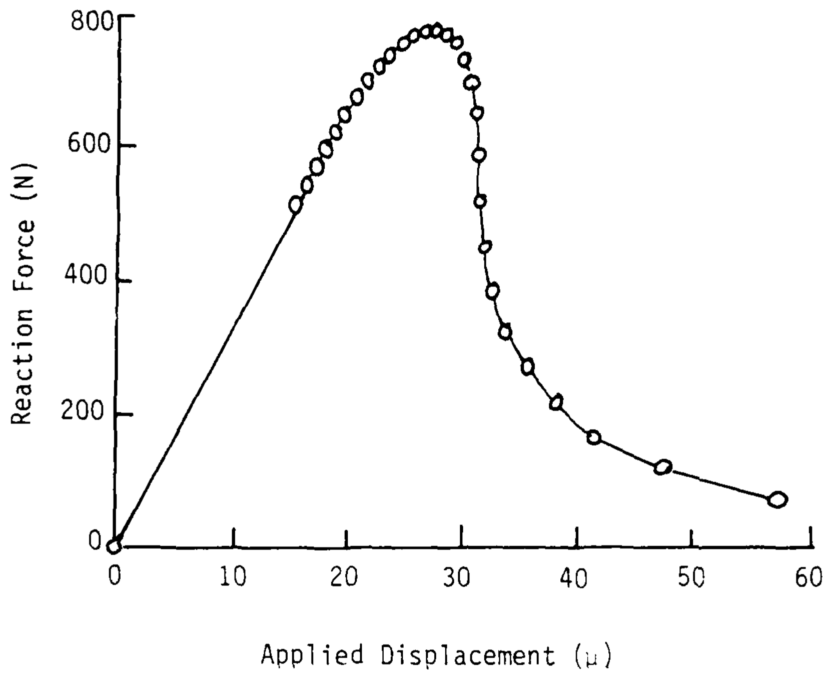


Figure 16. Reaction force versus applied displacement.

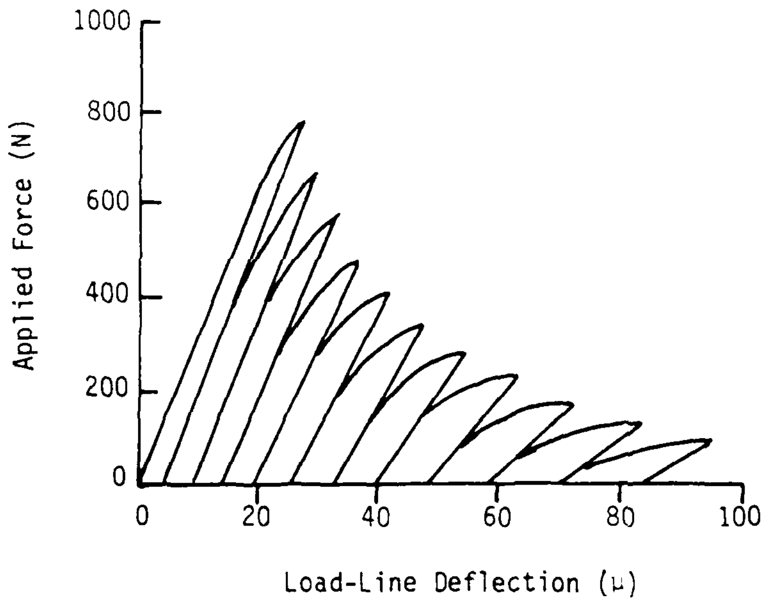


Figure 17. Cyclic flexural load--deflection curves.

Next he attempted to apply similar modelling to the crack run/arrest phenomenon in ceramic composites and in monolithic ceramic specimens. He showed that such crack closure stress is not sufficient to arrest a rapidly propagating crack that is driven by stored energy in a machined blunt notch specimen. However, in elevated temperature tests on a chevron-notched, three-point-bend, reaction-bonded silicon nitride specimen configuration, subcritical crack growth was achieved. In Figure 18, the solid curve is the calculated load versus the COD determined by finite element calculation of the fracture specimen. Note the agreement with the test data.

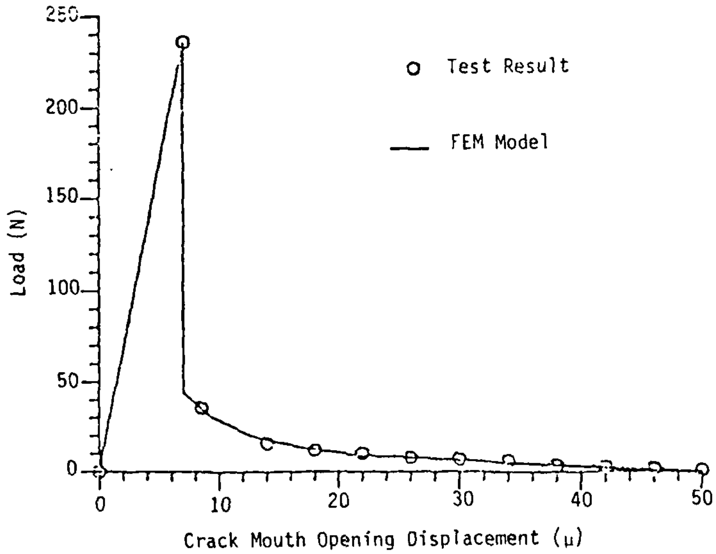


Figure 18. Load versus CMOD; RBSN prenotched bend specimen testing at 1,800 °C.

Kobayashi pointed out that with minor exception existing fracture mechanics analysis of structural ceramics is based on static data and static analysis of dynamic phenomena. Therefore, he has been investigating static versus dynamic fracture behavior. His previous studies of dynamic fracture in plate glass and reaction-bonded silicon nitride showed that the "vertical-stem," i.e., K_{Im}, does not exist in these brittle materials. In the present study, he demonstrated that in the wedge-loaded, modified-tapered, double-cantilever beam specimen it was not possible to arrest a propagating crack in reaction-bonded silicon nitride. Figure 19 indicates the difference in static and dynamic fracture toughness versus crack velocity.

More recently, he subjected alumina specimens to impact loading, using three-point-bend, prenotched specimens. Results of dynamic stress intensity factor versus crack velocity at room temperature are shown in Figure 20. Based on his studies, Kobayashi concluded that true static fracture toughness must be determined by using a specimen with a natural crack and that dynamic fracture behavior needs further investigation.

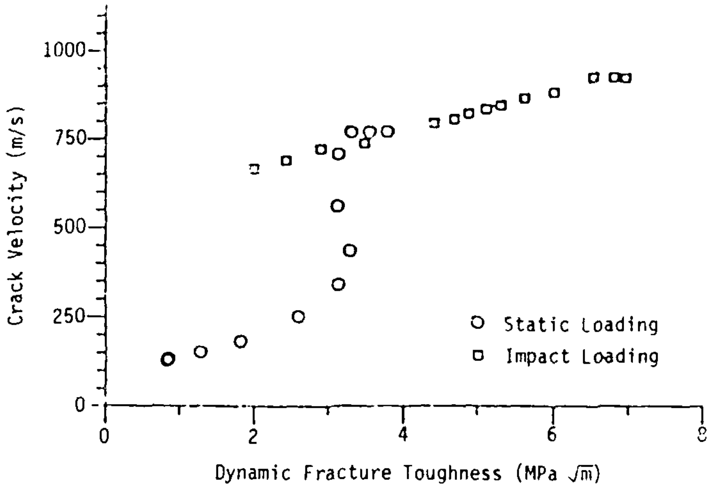


Figure 19. Dynamic fracture toughness versus crack velocity of blunt notch RBSN WL-MTDCB specimens.

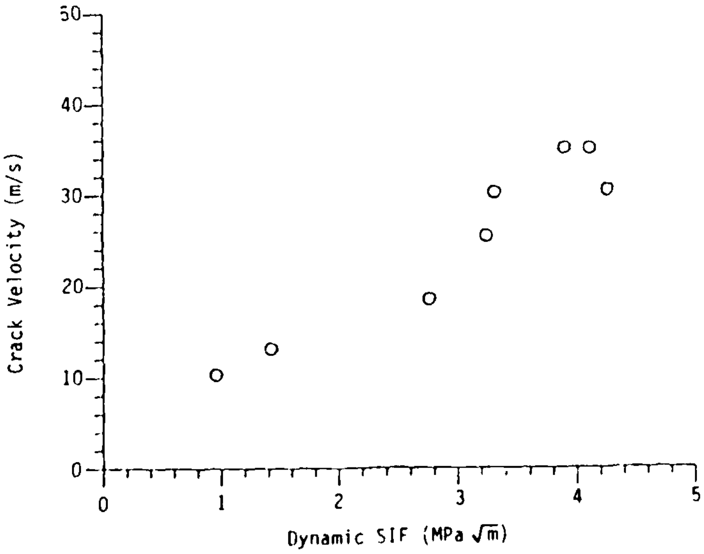


Figure 20. Dynamic SIF versus crack velocity.

Question:

You are using crack opening displacement (COD). But what if you have microcracks? You don't have a sharp unidirectional crack in that case. Thus, the COD will be larger because of these microcracks and the material will be more compliant.

Answer:

Yes, that's quite right! The fracture process zone we are postulating is just one line. Currently, we can only model this as a crack.

Question:

Why don't you model it using a strain energy release rate?

Answer:

If it's linear elastic fracture mechanics (LEFM), it's the same thing. But if you use the J-integral you are in trouble when the crack starts to propagate.

Comment:

No, I mean the terminology G, an energy term, which through the compliance you can calculate.

Answer:

Since we are measuring it works out to be the same thing; we just like to use the K_{Ic} terminology.

Question:

You have a rather horrendous conclusion, that there is no arrest! Do you think if you used a much larger chevron notch that there may be a size effect? In other words, is it because the energy that's driving the crack is so large in comparison to the crack surface area that you don't have the possibility of arrest? What would happen, do you think, if you went to a much different chevron notch configuration?

Answer:

In the blunt notch, whatever we do, there is enough driving force to overcome this. In metal fracture, there's a sufficiently large plastic zone, so that even with the same crack configuration you can arrest it. You can't do that with ceramics. With the chevron notch, as you can see when we went to an elevated temperature, we managed to get a strain softening effect. And likewise we should be able to, within that very bottom part, get the little pips to run and jump and arrest. So we can do that when there is a little bit of ductility. In other words, in regular through-notch specimens the bluntness, and the stored energy, drives the crack through. In the chevron notch we can get slight arrest with some ductility.

Question:

In your presentation you said that you needed a natural crack because the whole fracture mechanism will change unless it is a natural crack. I understand that you use a crack gauge. But in the case of crack advance the period of response of a gauge is pretty poor and there is significant distortion. We always find it difficult to capture the initiation of cracks with crack gauge. In the dynamic load configuration, what is the configuration for measuring the dynamic load? Also, are the K_{ic} values for static and dynamic situations different for the case of a dropping hammer?

Answer:

We are aware that the crack gauge drags behind, that it's delayed. It's generally adequate in metals because the COD is large enough. It does not work in ceramics. What I did not say is that after doing a lot of calculations, in computation the trace is slightly shifted (just based on experience). In metals we don't have to do that. I think our shift is about 15 percent in terms of time. So far our strain rate is small enough that we are getting the same apparent fracture toughness, which is probably consistent with brittle materials. We have not gone higher, but we are planning to use an air gun for loading. But then we will have to change the furnace completely.

Question:

How did you calibrate the strain gauge under dynamic loading?

Answer:

The load transducer is piezoelectric, statically calibrated.

Question:

You showed deflection curves with nonlinear behavior behind the fracture. This has been a point for many people who are developing microstructures just to make the behavior nonlinear, as it appears in a small specimen test. Unfortunately, all this behavior is mostly due to crack-surface modification and interaction in the long zone behind the crack tip, where all types of holding forces are acting. That means we are in reality beating the so-called K-concept. We should not use the K-concept in the case when we have crack-surface interaction. But all the "good" values that are now on the market, all the whisker reinforced materials and everything presently being praised, are principally based on crack-surface interaction. But are crack-surface interactions needed to increase the reliability of ceramics? Is that a philosophy or a concept that makes better ceramics?

Answer:

That's a topic for future workshops!

Baney

Dr. Baney provided a review of technology and research on organometallic routes to ceramic fibers for ceramic matrix composites. Included were Si–C, Si–C–N, and Si–N ceramic combinations. He briefly discussed key ceramic matrix problems including control of the fiber-matrix interface, mechanical strength during processing, thermal stability, and oxidation embrittlement.

Question:

What do you think the possibilities are for pressureless sintering of composites? It hasn't been done, but generally the other techniques you mentioned have problems.

Answer:

The requirement would be to get the temperature for pressureless sintering low enough. It's well known that Nicolon fiber decomposes above about 1,150 ^{o}C, giving off silicon monoxide and carbon monoxide, just as thermodynamics predicts, and that, of course, is the challenge to pressureless sinter at low enough temperatures.

Question:

You mentioned the importance of thermal expansion misfit between fiber and matrix. Is the misfit, in your opinion, wanted or not?

Answer:

I think what is important is not the weakening of the bond as the processing temperature is cooled down to room temperature for the interfacial interaction. However, this is the attempt that most have been trying to do, that is, make a weaker interface by having a mismatch favor a weak interface. In fact, what is important is the high temperature interface, and that is seldom addressed.

Question:

How is the infiltration accomplished? What is the degree of infiltration using whatever media, or organometallic vapors?

Answer:

These are not vapors. This is a polymer infiltration process. Preceramic polymers of the types that I reviewed are used to infiltrate the fiber, and initially they are coated, pressed, and then pyrolyzed. This leaves a large amount of voids. Then this part is recycled, the polymer is further infiltrated and pyrolyzed, and these steps are repeated maybe four or five cycles. This process is the same as the carbon-carbon processing technique.

CHAIRMEN SUMMARY COMMENTS

Professor Shimada

Five papers were given on the following topics: corrosion fatigue and lifetime (behavior), creep damage, static and dynamic fracture toughness, and ceramic fiber composite fabrication by the organometallic process. These papers reported on factors closely related to the ceramic microstructure and the role of the interface, grain boundary phases, pores, cracks, cavities, and bonding between matrix and fiber. These factors strongly influence the theological behavior, mechanical properties, and chemical stability at elevated temperature conditions. The evaluation of the theological behavior of ceramics, chemical reaction, high temperature creep, and slow crack growth under operating conditions are very important for high temperature structural ceramics when they are used in high temperature structural applications.

Unfortunately, to date, we do not frequently use ceramic materials as structural components in many structural applications. So we do not know which evaluations of ceramics as structural components are sufficiently fitting. Some studies on the evaluation of theological behavior are at a high level, but some research fields, such as stress corrosion, do not reach a sufficiently high level. In this situation, we should test ceramic materials under operating conditions as far as possible, and then we should have close, cooperating research work under processing, powder processing, and sintering. Evaluations of physical and chemical properties and microstructures to gain the most knowledge on theological behavior for structural applications are strongly required. This kind of research work is required to extend the future application of high temperature structural materials.

Dr. Fuller

Instead of thinking in terms of theology, I prefer to think in terms of the ceramics properties we need to design and reliably use ceramics. I prefer to characterize the papers under three categories: chemical stability, toughness and brittleness, and time-dependent behavior. Under the chemical stability category, I think corrosion testing is a very important area that we tend to neglect. It is particularly true if we are going to talk about ceramic engines working in environments with small amounts of alkalides. This is a very important area that needs continuing research.

In the brittleness and toughness category, we are concerned with various solutions about how to characterize it. One of the disadvantages of ceramics is that they tend to be brittle. How do we characterize the toughness, especially in small parts or components or small test specimens? Dr. Kobayashi addressed how to measure toughness in ceramics, both static and when the cracks are running, and the crack arrest phenomenon. He raised the issue about nonlinear fracture mechanics. But how do we do that, especially when we have small specimens? Maybe fracture mechanics only becomes a linear elastic fracture mechanics basis on which to extend other things.

Dr. Baney talked about ways to toughen materials by adding fiber into ceramic matrices. He raised one of the key issues of fiber stability. How do you

address the stability of the fiber and improve it? One of the other key issues is how do we densify a matrix around a ceramic preform or a fiber preform.

Time–dependent behavior, the final category, is a very important property of ceramics. If ceramics did not have time–dependent properties, then we could use their high strength and we wouldn't have to worry about them. Since they are time dependent, they tend to fail because of stress and time. Dr. Kawai talked about how you measure things at high temperatures and he characterized things in terms of crack growth, or creep crack growth in this case. I talked about similar types of things, except I was characterizing things in terms of damage. I think these are two regimes that we have to deal with at high temperatures. They are very important; they interact with each other.

CONCLUSION

During the workshop on Design, Analysis, and Reliability Prediction for Ceramics, much useful information was exchanged. In Part I, the first 10 papers presented at the workshop were discussed. The remaining sections on test and evaluation, advanced reliability methodology, and applications to mechanical parts will be reviewed in Vol 12, No. 1 of the Scientific Bulletin.

In Part II, eight papers by Japanese contributors, four by Americans and a Canadian, and three by Europeans will be reviewed, so that a wide spectrum of viewpoints will emerge. The presentations will serve to further demonstrate the broad range of activity, in–depth efforts, and diligence of the Japanese; the in–depth basic studies being pursued in the United States; and the practicality of the European counterparts.

A REVIEW OF COMPOSITE RESEARCH AND DEVELOPMENT IN CHINA

Tsu-Tao Loo

INTRODUCTION

Though a wave of interest in research on composite science and technology has only been on the uprise in recent years, research on composites in China, however, can be dated back to the late 1950s or early 1960s. In 1958, in response to a nationwide drive for new technology, glass fibers and composites were successfully developed and produced on a small scale through the auspices of the Chinese National Bureau of Structural Materials. The composite was named "Glass Steel" to symbolize its steellike strength.

Since 1958, glass-fiber composite technology has made considerable progress. The ensuing technical improvements to the products of the glass-fiber composite have been extended to a very broad area. Today, glass-fiber composite products in China include high-pressure oxygen containers, windmill blades, radar covers, small airplane propellers, and small antimagnetic ships. Moreover, some parts and instruments in space vehicles have been made of glass-fiber composites. These composites are also used to make special athletic equipment, such as vaulting poles, archer bows, and rowing boats, whereas other equipment, such as ski-boards and tennis rackets, are made from carbon-fiber composites.

To date, we have built several fairly large glass-fiber manufacturing plants and also established three major glass-fiber composite research institutes in, respectively, Beijing, Shanghai, and Harbin. The manufacturing processes include filament winding, hand lay-up, and moulding. The first texture of glass-fiber cloth to be manufactured was plain cross woven. Recently, unidirectional prepregs have been developed, but so far only one kind of prepreg with a rather narrow size is available. On the other hand, many technical problems remain to be solved (e.g., quality control, the standard or specification of the production, etc.), with much room for improvement. Our annual production of glass-fiber composites is much less than the amount of consumption, and it is far behind the production levels in the well-developed countries.

ADVANCED COMPOSITES

With regard to the development of advanced composites, the production technology for carbon fibers was developed in the mid-1970s. At this time, carbon-fiber-reinforced composites were introduced to the aircraft industry, where they are now used for vertical tails, nose cones, and other minor components of the aircraft. It is expected that in some airplanes the entire plane will be designed essentially with carbon-fiber-reinforced composites as the basic structural material. In addition, carbon-fiber composites are now expected to replace metallic alloys for rocket shells and various parts of communication or weather satellites (e.g., instrument supports, wing panels of solar-energy batteries, etc.). On the other hand, however, our carbon-fiber composites developed so far are only of moderate quality. For instance, in comparison with the Japanese T-300 fiber, both the strength and rigidity of our composites range

from 50 percent up to 70 to 80 percent at best. Besides, the material quality is not too stable and there are often large variations in properties. As for the three-dimensional carbon-carbon composites, only a very limited amount is produced and used for brake shoes. In contrast to the other composites, the boron-fiber-reinforced composite is being developed at a much slower pace in our country and is in the laboratory stage. As to the metal-matrix-based carbon-fiber composite, it was also developed in the early 1960s and the technology to control its quality has improved rapidly in the past few years. Presently, short fibers and hybrid fibers are being developed at a rather fast pace. Some sheet molding compounds (SMC) have been used by car manufacturers for window panels, seat cushions, etc. A few years ago, several new kinds of thermoplastic resins were developed. Also developed was Fanlon 1414, which possesses properties comparable with those of the well-known U.S. made Kevlar 29, which has the same strength, but twice the rigidity, of the glass-fiber composites. Other composites, like insulative materials used for the space shuttle, fiber-reinforced ceramics, silicon carbides, etc., are in the process of being developed or improved.

In nonmetallic composites, the resins are the most predominant matrix. The quality of the various types of resins made in our country is merely satisfactory. Both the variety and quantity manufactured are far behind the daily need. Moreover, only a few resins have been produced, and many new and important kinds, like PEEK, etc., have not as yet been developed. Lastly, it is worthy to mention that the production costs of all these composites, with the exception of glass-fiber composites, are considerably higher in our country, so that most of the composites can only be used for special purposes. In other words, our carbon-fiber and other advanced composites are so expensive that they have very little commercial value. At present, only glass-fiber composites have a wide range of applications in China. Only a few advanced composites are being used for special purposes, such as in airplanes, space vehicles, man-made satellites, and athletic equipment, and for some military purposes.

In summary, our composite science and technology today, particularly for advanced composites, is still lagging far behind the well-developed countries in quality, quantity, and manufacturing techniques.

FUTURE PLANS

Recently, our government has placed the development of new materials as one of the key items that has priority in the national construction plan. So the development of advanced composites will be given special attention during the current 5-year plan. Some government organizations have already encouraged and granted the funds to subsidize material manufacturers. There are plans to modernize the manufacturing plants and adopt new production processes. One of the approaches is to introduce advanced techniques from developed countries. For example, a production line of the French helicopter, named "Dolphin," was introduced in the early 1980s. The entire structure of this helicopter is made of fiber-reinforced composites. Hence, we are very optimistic in expecting the composite materials industry to gain momentum and to expand rapidly in the near future so that production will soon be greatly boosted. As a consequence, the cost may be greatly reduced to stimulate further areas of applications.

All this activity has sparked the interest and initiative of many scientists and engineers, including materials scientists, structural engineers, solid mechanicians, and chemists. Consequently, a large amount of research has been started in this field during recent years.

CONFERENCES, MEETINGS, AND PUBLICATIONS

Since 1980, we have already organized three national conferences on composite materials, once every other year, under the joint sponsorship of three national societies: Chinese Society of Theoretical and Applied Mechanics, Chinese Aeronautical Society, and Chinese Society of Astronautics. The first national conference on composite materials was held in 1980 at Beidahe. At that conference most of the participants were materials scientists. However, 2 years later, in the second national conference at Harbin, the situation was quite different--the structural engineers and solid mechanicians comprised more than 50 percent of the total attendance at the conference. A "Composite Wave" is thus formed. In this symposium and the forthcoming fourth national conference scheduled for the end of this year, more participants are anticipated. Besides the national conference, other special symposiums have been held under the sponsorship of individual societies and local district societies. Also, other composite meetings were convened by various ministries under their respective state councils. Formal proceedings were generally published after each national conference, whereas at small meetings reprints were distributed. Now we have several composite journals that are specifically publishing scientific papers on composite materials and structures. The first issue of the journal Acta Materiae Compositae Sinica appeared in 1984. Other journals, like Glass-Fiber Reinforced Plastics and Composites, had been published much earlier. In addition, there are several mechanics journals, such as Acta Mechanica Sinica, Mechanics and Practice, Acta Mechanica Solida Sinica, Journal of Applied Mathematics and Mechanics, Acta Aeronautica Et Astronautica Sinica, Shanghai Mechanics, and others also publishing some composite articles.

RESEARCH AND DESIGN ACTIVITIES AT UNIVERSITIES

Besides the glass-fiber composite research institutes, there are a number of other research and design institutions affiliated with various ministries also dealing partly with composites, such as the Institute of Materials under the Ministry of Aeronautics, the Institute of Mechanics under the Academy of Sciences, etc. Furthermore, at many universities and colleges, various groups of academic personnel devote themselves to research on composites and their structures. Usually a composite center or group is established in the department of materials science or mechanical engineering and in other departments. Hence, today we have a fairly large group of academic or technical personnel associated with composites.

Before the late 1970s, composite research was practically nonexistent in most universities. However, within recent years, most of the key universities in China have begun to offer courses like "Mechanics of Composite Materials," "Composite Materials," "Applied Elasticity for Anisotropic Bodies," etc. at either the undergraduate or graduate level or both. Sometimes a short course or workshop related to this topic is given. In the beginning, references for the courses were mostly taken from U.S. published books. Now in schools where the courses

have been offered several years, they are starting to use their own printed lecture notes. On the other hand, the experimental aspect of the work is still very limited in schools because of a lack of necessary equipment and materials for test specimens. Composite prepregs, autoclaves, and other facilities were not commercially available here until quite recently, and also advanced fibers are so expensive that most of the school laboratories cannot afford to use them. At any rate, with the government's encouragement, research projects on composites in schools sponsored by various organizations are growing at a very fast rate. As a result, the number of graduate students with good training in composite materials and mechanics is increasing greatly. Furthermore, we have already selected more than 50 scholars to visit various countries for special studies and research on composite materials. In the meantime, we have invited many specialists from overseas to give lectures and seminars on composites and their structures. They include Professors S. Tsai, C. T. Sun, R. Jones, A. Kelly, T. Hayashi, and many others.

CONCLUSION

All this new technology contrasts with the situation for decades--the work of a small group of people mainly devoted to manufacturing techniques and their practical applications. Indeed, the previous technology is an important aspect, but basic research or applied research, which has the greatest potential for improving or bettering the technology for tomorrow, is also an important aspect that cannot be neglected. Many technical problems require solution, such as selecting and developing the appropriate strength criterion, understanding failure mechanisms of the composites and laminates, and the interface bond between the phases in the composite. Further research is needed to solve these technical difficulties. The outlook for composite research and development in China is very promising, since we can expect more and more young scientists and engineers to join the composite materials group each year. The present research on composite materials and structures in China has already covered quite an extensive area, including environmental effects, hybrid fibers, thermoplastic composites, dynamic problems, metal-matrix composites, delaminations, damage and failure, as well as some experimental work.

To promote the advancement of our research and development effort on the science and technology of composites so as to keep up with the pace of modern progress, we need and welcome more international exchange of mutual experience and knowledge, both academic and technical. In the past few years, we have been an active participant in the U.S.-Japan joint conference on composite materials. And China is now a member country of the ICCM and will host the seventh ICCM conference in 1989.

ACKNOWLEDGMENT

This is only a brief review of the research and development on composite materials in China, based on the author's plenary talk at the opening ceremony of the International Symposium on Composite Materials and Structures held in Beijing, China, in June 1986. Thanks to Professors Z. Wang, Z. Gu, and F. Fan for their assistance in preparing this paper.

HYPERVELOCITY ACCELERATOR RESEARCH AT THE INSTITUTE OF PLASMA PHYSICS, NAGOYA UNIVERSITY

Kazunari Ikuta

INTRODUCTION

Hypervelocity accelerators are of interest for application to controlled nuclear fusion induced by the implosion of high velocity fuel pellets. The purpose of this paper is to review studies on the mass accelerator, which is designed for such impact fusion reactors, where the required velocity of a small projectile of about 1 gram is roughly 200 km/s. Since the size of the fuel pellet to be imploded by radiation pressure generated by hypervelocity impact is about 1 cm, the shape of the projectile should be in the form of a thin disc. This means that the position of an accelerating disc should be stabilized by its spinning motion and that the accelerator must be axially symmetrical to minimize its perturbation.

We are thus led to investigate a totally axisymmetrical accelerator system. One simple axisymmetrical accelerator would be the coaxial railgun, which needs a long inner rail with many mechanical supports. The presence of these supports destroys the axial symmetry of the system.

A novel kind of electromagnetic accelerator with axial symmetry is the ablation mass driver (AMD), which uses a single z-pinch between cylindrical electrodes (Ref 1). In the case of a high current discharge between cylindrical electrodes as shown in Figure 1, there should be a pair of plasma brims, connected to the plasma column, called the plasma stem. The brims propagate in the direction shown by the arrows. An accelerator composed of cylindrical electrodes is shown in Figure 2. The advantages of this axisymmetrical accelerator compared with the standard railgun (Ref 2) are as follows:

1. The plasma spilling over the nose of the projectile is inhibited because there is no gap for the plasma to penetrate past the projectile within the cylindrical electrode arrangement.

2. The acceleration force of the rocket effect and the resulting flow of plasma through the field-null-line of the azimuthal magnetic field are in the opposite direction to the projectile acceleration.

3. The breakdown voltage along the insulator surface between the electrodes does not depend on the size of the projectile (although the diameter of the projectile is the distance of the rails) so that small projectiles are rather difficult to accelerate using the railgun because of the low flashover voltage along the short insulator surface.

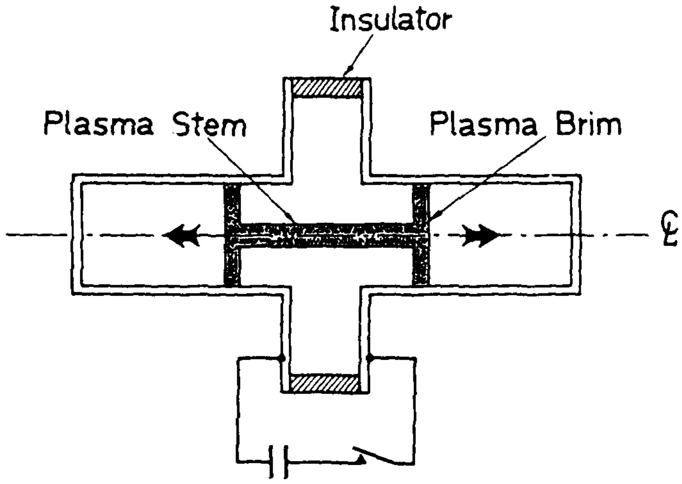


Figure 1. Schematic view of discharge with hollow electrodes. Provided the discharge current is high enough, the pinched plasma column (the plasma stem) with a pair of plasma brims should be seen in the cylindrical electrodes. The brims propagate in the direction shown by the arrows.

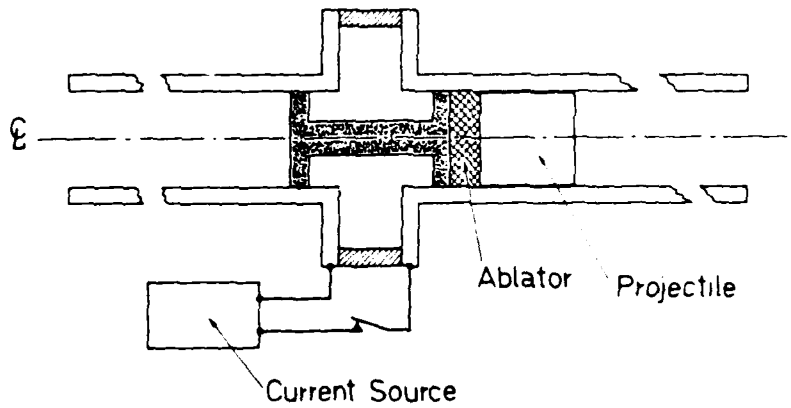


Figure 2. Principle of accelerations of a projectile using plasma brim. Note the presence of the ablator between the plasma brim and the projectile. The ablator will work both as an insulator preventing heat from passing from the plasma brim to the projectile and as the plasma source for the plasma armature.

ATTAINABLE VELOCITIES OF A PROJECTILE IN AN AXISYMMETRICAL ACCELERATOR

In this section we will establish the formula for the velocity increase of a projectile accelerated by the single z-pinch between cylindrical electrodes (Ref 3). This formula enables one to consider the necessary stages within the cylindrical electrode array of the accelerator for a required velocity.

Although the original AMD does not have a projectile injector that provides the initial velocity to the projectile in the first electrode in the cylindrical electrode array, we should think of using the injector in the first electrode since most of the electrode erosion occurs in the low velocity section of the accelerator. A schematic drawing of an improved AMD system is shown in Figure 3, which shows the explosive injector in the first electrode. This means that the projectile can have a velocity, v_0, along the axis of symmetry of the accelerator as an initial condition. This axis is taken to be the z axis in this work. Moreover, this new version has the cylindri cal insulators covered with ferromagnetic cylinders. These ferromag netic materials can increase the inductance of the discharge circuit by a factor of more than 1000 because the plasma current flowing through the cylindrical insulator magnetizes the ferromagnetic material if the resistivity of the material is sufficiently high. The rate of the current rise time of the circuit is now controllable by the occupied volume of the ferromagnetic material in the discharge chamber. At the same time the strength of the insulating cylinder for radially expanding force is significantly improved by the ferromagnetic cylinder as a guard ring.

The equation of motion of the projectile in the accelerating barrel is:

$$\frac{d}{dt}\left(M \frac{dz}{dt}\right) = \frac{\mu_0}{2}\frac{I^2}{\pi} \ln\left(\frac{a}{r_p}\right) \qquad (1)$$

where: I = total current in the plasma brim

M = mass of the projectile including ablator and the plasma

a = radius of the cylindrical barrel

r_p = the radius of plasma stem

Here the skin plasma current along the plasma stem is assumed. The quantity μ_0 is the magnetic permeability of vacuum.

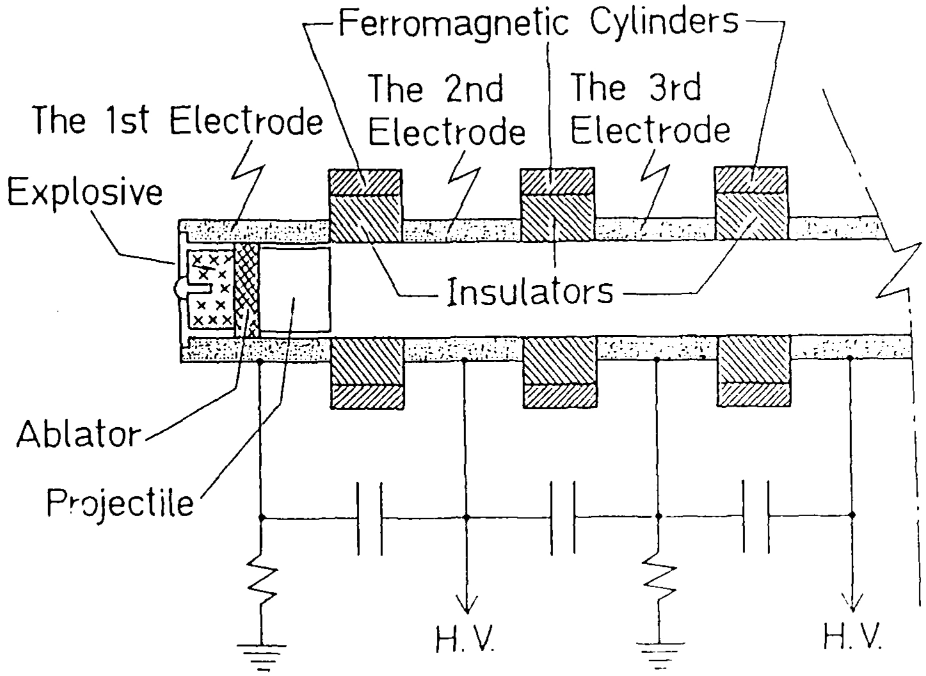


Figure 3. Schematic drawing of an electromagnetic accelerator with both the explosive injector and the ferromagnetic guard ring for the insulator cylinders.

The equation for the plasma current is:

$$\frac{d^2}{dt^2}(L\ I) + \frac{I}{C} = 0 \tag{2}$$

where L is the inductance of the circuit including the plasma column, the ferromagnetic cylinder, and the current-carrying barrel, and C is the capacitance of the capacitor as a current source. Initially, i.e., at $t = 0$, the capacitor is charged up to the voltage, V_0, by a high-voltage generator.

By a straightforward but tedious calculation of Equations 1 and 2, we obtain that the increase of project velocity, Δv, in the second electrode tends to be:

$$\Delta v \equiv \frac{dz}{dt} - v_0 \rightarrow \frac{C\ V_0^2}{2}/(2\ M\ v_0) \tag{3}$$

A physical meaning of Expression 3 is that the increase of projectile velocity in a single electrode is the ratio between the energy supplied by the capacitor and two times the injected momentum into the accelerating electrode. Expression 3 enables one to consider the stages of the accelerator necessary for a required velocity.

In general, we can show the velocity of the projectile in an accelerator with n-th accelerating gaps as follows. From Expression 3 we write the velocity increase in the j-th electrode as:

$$(\Delta v)_j = \frac{A_j}{v_{j-1}} \tag{4}$$

where

$$A_j \equiv \frac{C\,V_o^2}{4\,M}$$

v_{j-1} is the velocity of the projectile at the inlet of the (j+1)-th electrode. The final velocity, v_n, accelerated by the n-staged accelerator is described by:

$$v_n = v_o + \sum_{j=1}^{n} (\Delta v)_j \tag{5}$$

Using Formula 5, the final velocity attained in a five-stage accelerator that is being planned to be built at Lubbock becomes, as an example,

$$v_5 = v_o \left[1+\gamma + \frac{\gamma}{1+\gamma} + \frac{\gamma}{1+\gamma+\frac{\gamma}{1+\gamma}} + \frac{\gamma}{1+\gamma+\frac{\gamma}{1+\gamma}+\frac{\gamma}{1+\gamma+\frac{\gamma}{1+\gamma}}} \right.$$
$$\left. + \frac{\gamma}{1+\gamma+\frac{\gamma}{1+\gamma}+\frac{\gamma}{1+\gamma+\frac{\gamma}{1+\gamma}}+\frac{\gamma}{1+\gamma+\frac{\gamma}{1+\gamma}+\frac{\gamma}{1+\gamma+\frac{\gamma}{1+\gamma}}}} \right] \tag{6}$$

where γ is assumed to be a constant defined by

$$\gamma \equiv (C\,V_o^2)/(4\,M\,v_o^2) \tag{7}$$

SELF-CROWBARRING ELECTROMAGNETIC ACCELERATOR (Ref 4)

There are two kinds of energy sources for operating electromagnetic accelerators: capacitive and inductive energy storage systems. Capacitive energy storage systems are superior to inductive energy storage systems in that the capacitive systems need no opening switches to deliver energy from the energy source. Moreover, recent progress in capacitor technology has made a high energy density capacitor possible, and the volume of the capacitor bank can compete with the volume of the inductive energy system, such as homopolar generators, provided that the bank is constructed of these high energy density capacitors. One disadvantage of the high energy density capacitors is their low voltage reversal in order to use them as the components of a long life capacitor

bank. This means that the use of the crowbarring switch for discharge is inevitable to lengthen the life of the high density capacitors.

A novel kind of electromagentic launcher for the acceleration of a projectile to hypervelocities is designed by using a periodic z-pinch between the cylindrical electrodes (Ref 1).

To demonstrate nuclear fusion using the hypervelocity impact of a projectile with the D-T ice pellet, the energy becomes on the order of 50 MJ. If this energy is supplied by a capacitor bank, the volume of the bank becomes gigantic, provided that the low energy density capacitors are the components of the energy source. Using higher energy density capacitors is desirable for a less voluminous energy source. In this case the crowbarring circuit should be installed in the accelerator system. Note that the large number of required expensive switching elements makes the cost of the accelerator prohibiive. To overcome this financial problem of constructing the accelerator, the self-crowbarring accelerator system should be investigated.

The principle of a single-stage self-crowbarring accelerator is shown in Figure 4. Note the presence of the massive materials (i.e., the projectile and the ablator) in front of one of the plasma brims. This means that the velocity of one plasma brim is very much slower than the other one. This situation gives us an opportunity to take the long rise time of the current along the plasma column before the crowbar. The rise time of the plasma current can be controlled by the inductance of the multi-turn solenoid embedded in the cylindrical insulator as is also shown in Figure 4. This solenoid can generate an axial magnetic field in the cylindrical electrode, and the presence of an azimuthal magnetic field in the cylindrical electrode may change the forward thrust of the projectile, since the axial magnetic field can act to constrict the plasma stem and the contriction can increase the radial plasma current, which gives the axial force to the projectile.

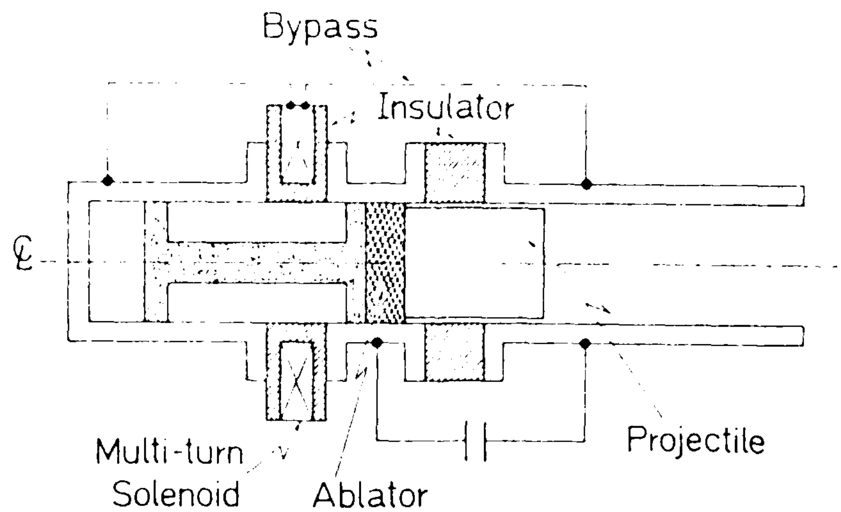


Figure 4. The principle of a single-stage self-crowbarring accelerator. Note the presence of a multi-turn solenoid that generates the axial magnetic field in the cylindrical electrodes.

In the original ablation mass driver (Ref 3), we need Q number of high power resistors to keep the potential of every capacitor floating, where Q is the number of stages of the accelerator and is about equal to 100 in the real accelerator system. This situation of keeping every capacitor isolated makes the structure of the accelerator quite complicated. This complexity is relaxed in the case of the self-crowbarring ablation mass driver. A schematic diagram of the self-crowbarring accelerator is shown in Figure 5, where every capacitor is connected to the ground potential through coil windings. Here a projectile made of an.insulator is loaded with an explosive in the first electrode called the "starter electrode." The adoption of the starter electrode in the z-pinch accelerator makes the repetitive injection of projectile into the accelerating electrodes possible because a cylinder of several chambers could work as the starter electrode, where every loaded chamber is brought successively into line with the accelerating electrode and discharged with the same hummer. This situation is quite similar to the revolver. The technique of the breech loader is also applicable. Once the explosive is fired by some means, this acts as a source of weakly ionized plasma that pushes the projectile into the array of the acceleration electrodes and the coils. The weakly ionized plasmas will be fully ionized by the strong electric current from the capacitors. This strong current will also heat the tail of the projectile, and the ablation materials ejected into the starter electrode can give the forward thrust to the survived part of the projectile like that of the chemical rocket (Ref 5). The time sequence of the projectile acceleration is easily controlled by the choice of capacitances, the inductances of the capacitors, and the coils, respectively.

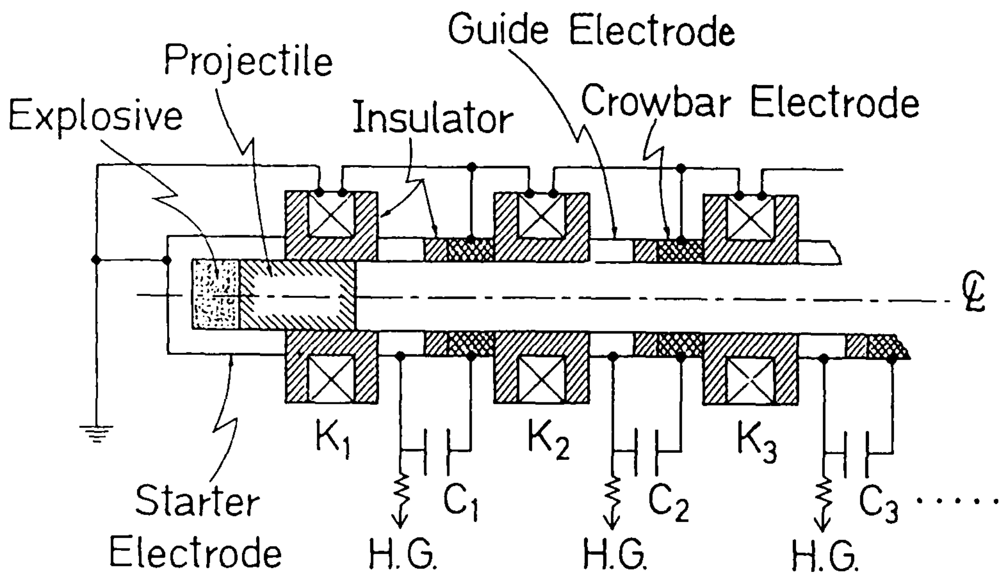


Figure 5. Schematic drawing of a multi-stage self-crowbarring accelerator system. Note that the electric potential of the multi-turn solenoids is the ground level. In this case the explosive is loaded behind the projectile in the starter electrode to give the initial velocity to the projectile.

SUMMARY

The scheme of accelerating a projectile by electromagnetic means in axisymmetrical geometry is theoretically established both from the viewpoints of plasma physics and pulsed power technology. A comparative study between the rail gun and the axisymmetrical accelerator will become possible in the near future when the five-stage, 1-MJ accelerator is built in Lubbock, TX.

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RECENT DEVELOPMENTS AT FOUR JAPANESE FACILITIES

J.D. Hightower and Sandy Kawano

EDITOR'S NOTE

J.D. Hightower, of the Naval Ocean Systems Center, Hawaii Laboratory, visited four facilities during his trip to Japan in June 1986. At the Seiko-Epson facility at Suwa, a high-resolution, compact, LCD color video projection system was demonstrated and discussed. The Ministry of International Trade and Industry's (MITI) Mechanical Engineering Laboratory (MEL) at Tsukuba provided information on their approach to development of remote presence (which they call tele-existence) systems. This effort is part of Japan's national telerobotics program called Advanced Robot Technology (ART) being promoted by the Agency of Industrial Science and Technology, MITI. The Japan Marine Science and Technology Center (JAMSTEC) provided information on the status of both their new unmanned and manned submersibles and on their tether cable test results for the DOLPHIN unmanned submersible. At Mitsui's Chiba Shipyard, a small SWATH-configured yacht was demonstrated and a new hovercraft design was discussed. The following sections are condensed from a trip report submitted by Mr. Hightower highlighting the major observations during his site visits.

SEIKO-EPSON PLANT, SUWA

At Seiko-Epson a new compact projection TV system (Figure 1) was demonstrated and discussed. The technology involved in producing a video projector this small is very impressive. The prototype model demonstrated had a line resolution of 320 x 220, and in about 1 year they expect to have 480 x 440. Plans for the current model include a limited production run during the summer (1986) for a market sample evaluation. These units will probably be available in September. The light valve arrays use the relatively new thin film transistor technology (TFT) liquid crystal (LC) light valve technology and currently are producing pixel sizes of 80 by 90 microns. These TFT LC valves have the desirable qualities of high contrast ratio and durability to intense light along with high pixel density and relatively low cost. In about 1 year, they expect to be able to make experimental 4- by 4-inch LCDs with 50-micron pixels yielding 2,000-line resolution. Their goal is to eventually make 6- by 6-inch LCD light valves. Custom units can be made, if desired, but costs would be high. Seiko-Epson expressed interest and supports our systems research efforts using their prototypes and the potential market applications that may result.

MECHANICAL ENGINEERING LABORATORY (MEL), TSUKUBA

The MEL teleoperated land vehicle is operated in and around the parking lot from a control station inside the laboratory. The control station (Figure 2) includes a one-degree-of-freedom (pan or yaw) color stereo display, binaural headphones, and a model airplane joystick control. The stereo display is mounted on a low friction bearing but has to be panned with assistance by the left hand.

The one-degree-of-freedom stereo vision display uses two 4-inch Sony color monitors with folded optics to achieve human interoccular dimensions. Even though the resolution of 4-inch color monitors is not as high as one might want, it was very effective to view the remote scene in color. The vehicle control for forward speed and left-right turning was proportional to joystick displacement from neutral and was very smooth and quickly accommodated. The vehicle (Figure 3) has a U-shaped forward boom with a small vertical tab that is usually in the field of view. It is nearly impossible to maneuver the vehicle without hitting obstacles if there is not a vehicle reference in the driven field of view.

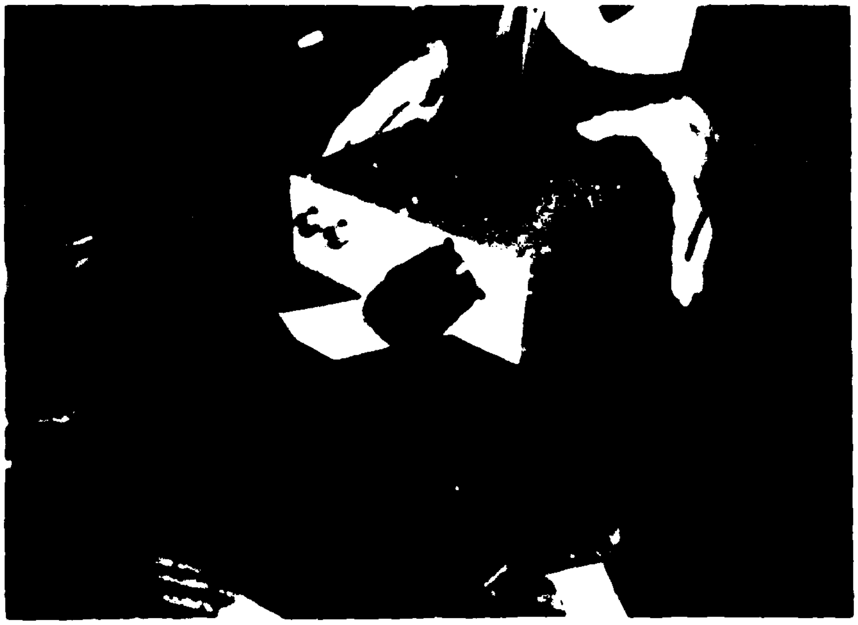

Figure 1. New Seiko-Epson compact color video projector.

The data links for control and video are RF. Vehicle control uses a VHF channel with a NEC PC (Figure 4) and modems, while the stereo TV uses two commercial UHF TV channels. Video fade occurred a couple of times during the demonstration. While not a problem for driving in the short demonstration, it brought to mind the weakness inherent in RF video links.

MEL has done previous work with a five-degree-of-freedom goniometer head coupled/servoed display, and soon they plan to investigate a six- degree-of-freedom unit with pitch, yaw, roll, and X, Y, Z linear dis- placement. MEL researchers are strongly advocating a stereo vision system with an auto convergence feature for work and observation of objects 2 to 3 meters or closer. On the present demo an IR object range finder system is used to close the loop on the camera convergence angle. At the display end the mirrors are servoed to change angle.

Figure 2. MEL teleoperated land vehicle control station.

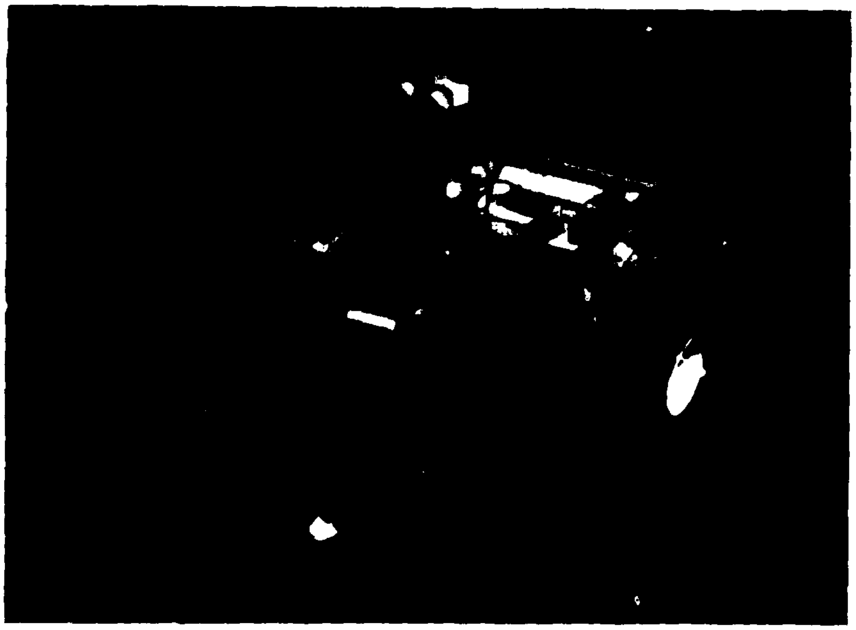

Figure 3. MEL teleoperated land vehicle.

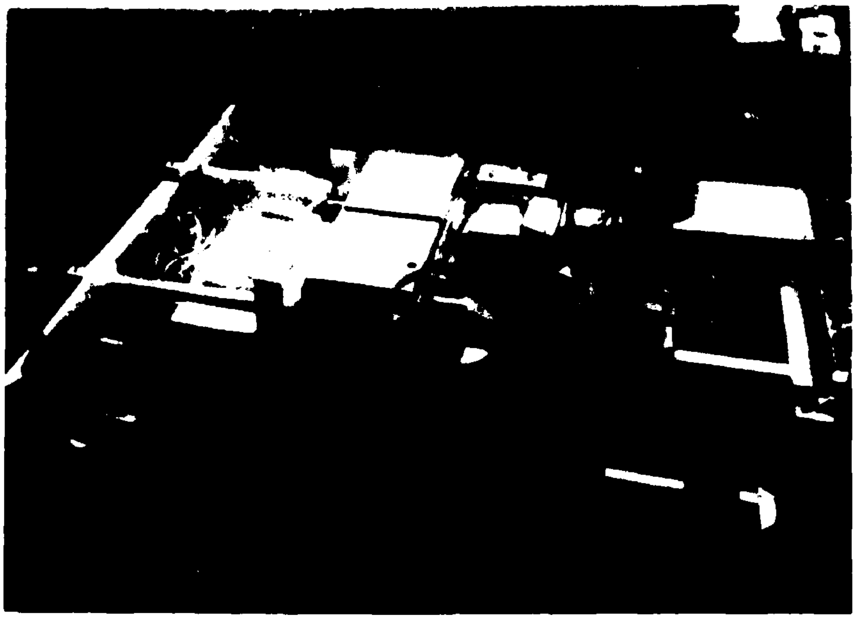

Figure 4. Close-up of MEL vehicle showing NEC PC and modems and the two UHF antennas.

Other projects in progress include preliminary work on a five-finger hand with steel microcable tendon driven digits and a Polhemus magnetic beam tracking system used as an end effector controller (master) driving a computer-generated display of a manipulator.

At least a portion of all this work is funded by and connected with the Japanese national research and development project called Advanced Robot Technology (ART). Many of the big industrial giants of Japan are involved. I was told that Hitachi is working on legged locomotion, Mitsui is working on undersea vehicles, and Mitsubishi is working on hands/arms, etc. The ART program is aimed at providing robots or teleoperators that are practical for use in several broad areas generally inhospitable to humans: (1) nuclear, (2) undersea, and (3) disaster control, such as fire.

JAPAN MARINE SCIENCE AND TECHNOLOGY CENTER (JAMSTEC), YOKOSUKA

JAMSTEC has recently completed design of a manned submersible that will have a 6,500-meter depth capability. Construction under contract is scheduled to start in mid-FY86, with delivery to JAMSTEC expected in mid-FY89 following acceptance sea trials. The pressure hull will use the titanium alloy Ti-6Al-4VELI. Extensive pressure tests have been run on spherical models to verify design requirements. The final full-scale pressure hull will be built in Japan by Kobe Seiko and Mitsubishi with proof testing done at the David Taylor Naval Ship Research and Development Center, Annapolis, MD. JAMSTEC is now

in the process of doing system trades to select a support ship. Choices are: (1) using the existing SHINKAI support ship NATSUSHIMA, (2) using the SWATH ship KAIYO, or (3) building a new ship. If a new ship is built, I was told, it probably will not be a SWATH because the water depth at JAMSTEC is too shallow to accommodate trim changes when using an onboard crane to on/offload a submersible as heavy as a SHINKAI. Presumably, the new submersible (no name yet, but probably SHINKAI 6000) is even bigger.

The DOLPHIN 3K (a 3,000-meter unmanned, cable-tethered vehicle) program is on schedule with the first in-water tests scheduled for January-February 1987, followed by deep-water tests to 3,300 meters in March. The titanium frame is now at Mitsui for final fit-up as shown in Figure 5. The vehicle will have a stereo black-and-white HCTV system built by Japan Radio Company, Tokyo. Also, it will have a monocular color HCTV built by SIMON. The manipulator with seven degrees-of-freedom has force reflection in the gripper and the first three joints. The master has a pistol grip for the parallel jaw gripper, which has a grip force of 7 kg. The material is 6061 aluminum. The master is shown in Figure 6.

Figure 5. DOLPHIN 3K titanium frame with various components being added.

The DOLPHIN tether cable has been completed by Fujikura and was tested in April. The 30-mm-diameter cable has a breaking strength of 23 tons provided by Kevlar contained between ethylene-polypropylene jackets. Four optical fibers are contained in spiral grooves in ABS plastic rod overjacketed with an ABS tube without void filler.

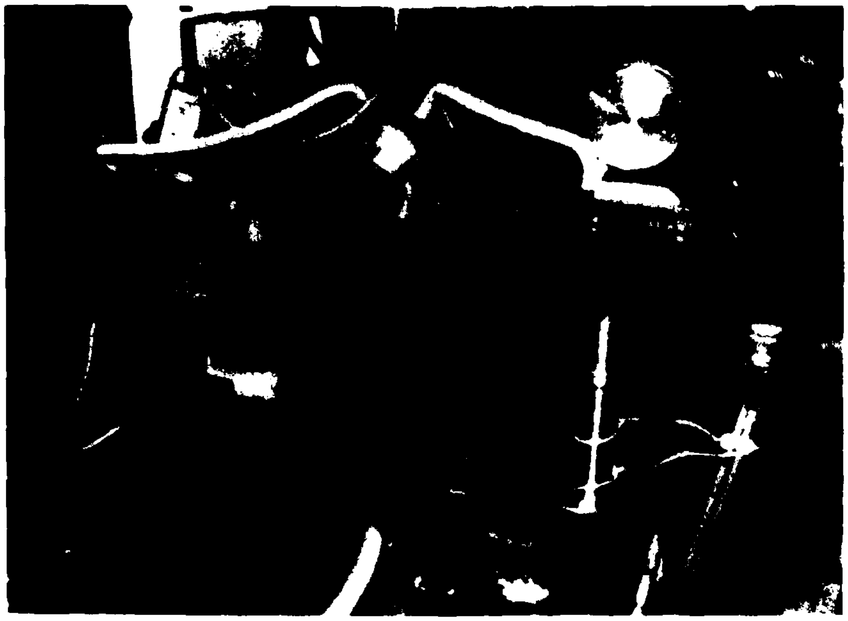

Figure 6. DOLPHIN 3K manipulator master controller.

No problems were encountered in the cable pressure test. They have successfully completed an accelerated flex test loaded at 10 tons for 5,000 cycles assuming this will duplicate the design goal of 500,000 cycles at 2 tons. The optical penetrators used are made by Daiichi Denshi Kogyo, DDK model 115J, and are epoxy sealed in an alignment groove and then polished. One half spring is loaded to provide firm contact between the two halves.

I was shown a movie of cable handling tests that were run on the SWATH support ship KAIYO. The system uses a ram tensioner with a separate traction winch and cable storage reel and a deck sheave or two. Threading the cable over and through everything appeared to be somewhat difficult. During these tests, two different optical slipsprings made by DDK were tried. Interestingly, the standard off-the-shelf model worked better than a special design.

JAMSTEC has completed the design of yet another small FO-tethered inspection vehicle to be built by Sumitomo over the next 2 years. No details were available except it is supposed to have a 2,000-meter depth capability. Another vehicle is being built now for Kokusudai Denshin Denwa Company, Ltd. (KDD), apparently for cable inspection. The vehicle has a depth capability of 2,500 meters. Mitsubishi Heavy Industry is building the vehicle, and Furukawa is manufacturing the cable. It is expected to be completed by May or June 1987.

MITSUI, CHIBA SHIPYARD

A demonstration ride was taken on the small 16-meter SWATH-configured yacht MARINE WAVE, which was built as a promotional device for Toray Company. The craft, shown in Figure 7, is very classy in appearance and features a composite hull construction using both fiberglass and some of Toray's own carbon fiber in epoxy. While out in Tokyo Bay, 2- to 3-foot waves were encountered at various headings and speeds. The ride stability was very good and obviously much better than a comparable sized monohull. The boat has four stabilizing fins or canards with only the forward two being controllable. Last April the MARINE WAVE was taken on a 2-day run to Osaka, where it encountered waves up to 4.5 meters. Even though this was a factor of 3 greater than the design height of 1.5 meters, the boat survived in good shape. According to the first mate, the boat could handle up to 2.5-meter head seas relatively easily. In waves much higher than 1 meter, however, stern quartering runs were found to be uncomfortable. A redesign of the forward strut/hull area is underway and is expected to fix that problem. The boat was smooth and quiet, with a top speed of 18 knots provided by two 250-hp Ford marine diesel engines.

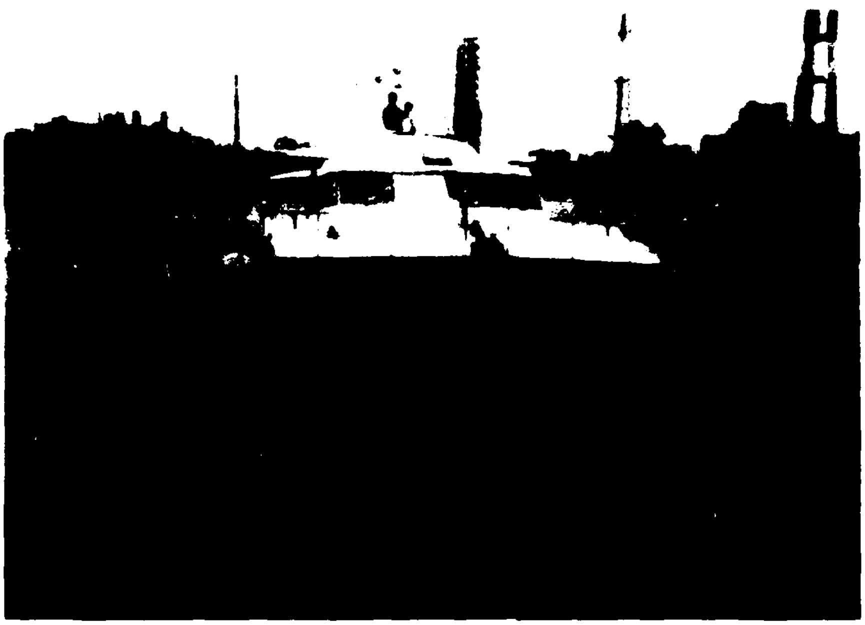

Figure 7. MARINE WAVE, composite hulled 16-meter LOA SWATH ship.

Given the fact that the hull is nonmetallic and deck space and useful volume is so large (Figure 8), it would seem a craft like this is ideally suited to the spec war swimmers or as an inshore small MCM. The U.S. Navy might benefit by leasing this craft to evaluate a small SWATH design.

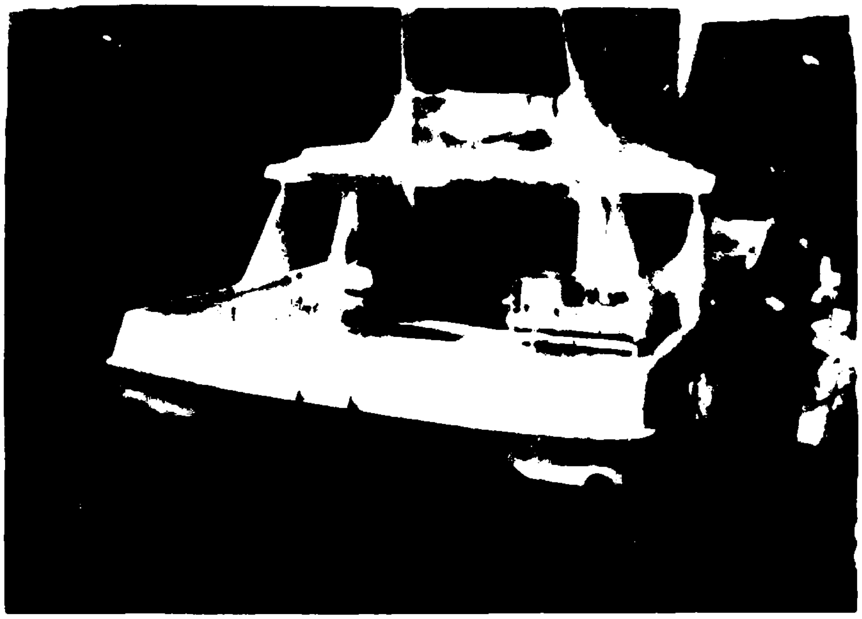

Figure 8. Stern view of MARINE WAVE showing roomy deck and cabin.

The new hovercraft design (Figure 9) was interesting, with the usual inflated rubber skirt that surrounds the perimeter of a hovercraft being used only on the forward two-thirds of the craft and across the bow. The aft third of each side was a submerged skeg rather like a small SWATH ship strut. Each aft skeg contained a water jet propulsion unit (or could have a standard propeller and rudder) and provided increased lateral stability in turns. This experimental 12-meter prototype was equipped with both passive and active cushion pressure relief systems (Figure 10) to adjust ride stiffness. This craft was much quieter and did not vibrate like air propeller versions. Mitsui may make a much larger passenger/auto ferry version of this new design that is about 40 meters long.

(a) At pier.

(b) Underway.

Figure 9. New hovercraft.

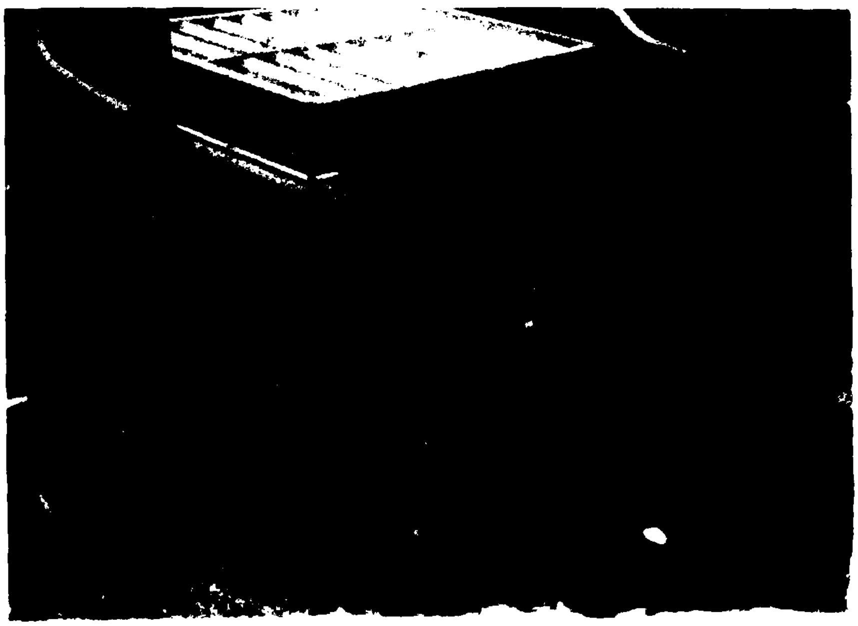

Figure 10. Experimenta[illegible]
with bott[illegible]

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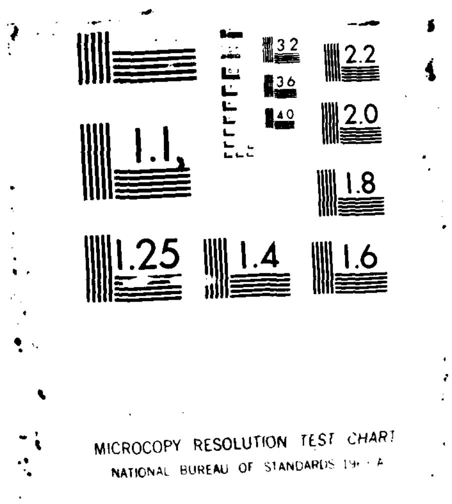
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THE TENTH IEEE INTERNATIONAL SEMICONDUCTOR LASER CONFERENCE

George B. Wright

INTRODUCTION

The Tenth IEEE International Semiconductor Laser Conference, held in Kanazawa October 14–17, 1986, was one of a topical series which began in 1967 in Las Vegas. Succeeding meetings were at Mexico City in 1969, Boston in 1972, Atlanta in 1974, Nemunosato in 1976, San Francisco in 1978, Brighton in 1980, Ottawa in 1982, and Rio de Janeiro in 1984. The next conference is planned for Boston in 1988. As can be seen, this is a truly international conference series, and this was reflected in the authorship of the papers submitted this time. Since the first successful semiconductor lasers were invented in 1962, and only worked on a pulsed basis at low temperatures, the early conferences were much concerned with fundamental questions about the mechanisms and modes of operation. By the time of the present conference, continuous wave (CW) operation at room temperature is commonplace, efficiencies are high, and the flavor of the conference was very much directed to meeting systems requirements for applications in optical communication. The true measure of early scientific success is that we have now moved to engineering.

The participants list showed a total registration of about 377, of whom 220 were from Japan, 75 from the United States, and 18 from the Federal Republic of Germany (FRG). The remaining participants came from 18 other countries in groups of 9, 7(2), 6(2), 5, 4(2), 3(2), 2(2), 1(6); the number in parentheses is the number of countries represented by a group of that size.

A booklet of extended abstracts was provided at the beginning of the conference for the 99 15-minute contributed papers and 7 postdeadline papers. The rump session seemed to this participant to be several more brief contributions. With this number of papers, the committee was able to avoid parallel sessions by starting at 8:15 and running sometimes to 9:30 p.m. Luncheon breaks, coffee breaks, and dinner breaks allowed opportunities for discussions between participants, while a small interval at night was available for knitting up the ravelled sleeve of care. For cultural enrichment, we were treated to a splendid "Noh" performance at Kanazawa's dedicated Noh theater, and at the sit-down banquet we saw an outstanding presentation of myriad styles of Japanese kimonos. One is left with a strong desire to return to Kanazawa.

Of the 99 regular papers, 47 were from Japan; 30 from the U.S.; 5 from the FRG; 3 each from China, the U.K., and the U.S.S.R.; 2 each from France and The Netherlands; and 1 each from Brazil, Canada, Italy, and Sweden. However, there was a remarkable national clustering by topic, which perhaps reflects national effort. Since the Japanese and U.S. contributions dominated the total, the easiest way to show this is to list each topical session, with the count of Japanese and U.S. papers for each topic. A balanced effort would be represented by about two U.S. papers and three Japanese papers per session. Session K on high power lasers was entirely Japanese, while Sessions A, B, E, and G came close. As an indication of the vigor of Japanese research in this area, one eminent researcher suggested that a count of the Japanese authors alone might exceed the total of U.S. workers in the field, but I did not make this count.

The list of session topics, with the count of U.S. and Japanese papers, is as follows:

Session Topic	U.S.A.	Japan
Plenary Opening Session		
A. Visible and GaAlAs Lasers	0	5
B. Integrated Lasers	0	5
C. Linewidth and Chirping	4	1
D. Materials	2	2
Rump Session		
E. DFB Lasers I	0	6
F. Narrow Beam Lasers and Arrays	3	3
G. DFB Lasers II	0	5
H. Monolithic Cavity Lasers	2	3
Postdeadline Papers		
I. External Cavity Lasers	6	0
J. Bistability and Amplifiers	0	2
K. High Power Lasers	0	6
L. Miscellaneous	2	1
M. High Frequency Modulation	5	2
N. Instability and Noise	2	3
O. Quantum Well Devices	1	3
P. InGaAsP and Longer Wavelength Lasers	4	0

The smooth organization of the conference and the high quality of the papers are a tribute to the General Chairman, Professor Yasuharu Suematsu of Tokyo Institute of Technology, to Dr. Ivan Kaminow, the Program Committee Chairman, and to the dedicated members of the committees who worked so hard to make it happen.

TECHNICAL PROLOGUE

Research on the science and engineering of semiconductor lasers is a very specialized, highly technical field, involving an understanding of the electronic properties of semiconductors, modern optics with quantum effects, the art of materials preparation and, increasingly, an understanding of communications engineering. And yet, since this report is directed to rather a wider set of readers than those who are simultaneous masters of all the fields mentioned, I think it useful to make a brief "suggestive" review of some of the fundamental principles involved, so that the interested reader may obtain an idea of what was done at this conference.

Semiconductor Laser Diodes

All of the lasers of importance at this conference are electrically excited by injection of excess electrons and holes into a semiconducting p-n junction. The electrons recombine with the holes, emitting photons with energy roughly equal to the energy gap of the semiconductor. The spatial region of recombination is called the active region, and a light wave propagating through this region will experience optical gain. It is important to note that there are nonradiative recombination mechanisms present, which represent losses. When the gain balances the losses due to other causes, laser action results. The cur- rent at which this occurs is called the threshold current, and it is very important to make this as low as possible. Lasers with low threshold can operate at room temperature continuous wave (CW), as opposed to low temperature, pulsed operation. The advantages of the former for practical applications are obvious.

Optical Cavities

Normally, it is necessary to provide some sort of resonant optical cavity so that the light wave may make multiple traversals of the gain region. The simplest form of cavity is provided by mirrors at each end of the cavity. These may be as simple as the discontinuity of refractive index at the semiconductor-air interface, or there may be additional coatings. Another form of optical feedback is provided by diffraction gratings formed in the optical cavity. One type is the distributed Bragg reflector (DBR). Lasers using gratings are called distributed feedback (DFB) lasers (Sessions E and G). The spectral linewidth of the emitted light is proportional to the loss in the cavity, and to get very narrow linewidths, some lasers are built with external cavities, or extended cavities (EC) (Session I). This may be very important for communication systems that require spectral multiplexing.

The distribution of light intensity in the cavity is determined by the normal modes of the cavity and may be separated into longitudinal modes and transverse modes. A new longitudinal mode is added every time the light frequency increases enough to make the cavity length one-half wavelength longer. These modes are close together in frequency and must be controlled (suppressed) in many communication applications. The transverse modes are governed by the width of the cavity (active region). Normally, there is a threshold frequency (cutoff) below which no modes are excited. When the frequency is increased to make the active region about one-half wavelength wide, the first mode appears. It would be desirable to make the active region about this width, but fabrication difficulties are very great (paper E-4). Excitation of multiple modes can lead to instability of laser operation. The transverse mode pattern has an important influence on the external beam width of the laser (Session F), and great improvements can be obtained by going to arrays of coupled lasers. It is also possible to get higher total output power by using arrays of lasers.

Semiconductor Materials

The first successful semiconductor lasers reported were made in GaAs, a direct gap semiconductor with a band gap energy around 1.5 eV at low temperature, emitting at a wavelength around 0.8 micron (very near infrared). For applications, it would be very desirable to have lasers at wavelengths around

1.5 microns near the minimum of loss in optical fibers to be used in communications systems, and in the 0.4- to 0.7-micron visible light region for displays and for reading optical disks. High power is desirable for writing optical disks and for facsimile and xerography.

Engineering Energy Bandgaps

Alloys. To obtain new wavelengths, it is necessary to change the semiconductor energy gap, but only a small number of semiconductors are potentially useful. It is possible by alloying two semiconductors to obtain an alloy with an energy gap intermediate to the endpoints and roughly proportional to the composition. The lattice constant in a binary alloy will also be proportional to the composition (Vegard's Law). Growing semiconductor alloys of high quality is very difficult. Epitaxial growth, in which the lattice constant of the alloy being grown matches that of the substrate crystal upon which it is grown, leads people to grow ternary, and even quaternary, alloys in an effort to match the lattice constant of the substrate while getting the desired bandgap. Of course, these complicated alloys are very expensive to develop to usable quality. In any case, whenever we see a paper involving an alloy of peculiar composition, its choice can usually be traced to the desire to get a given bandgap-lattice constant combination.

Double Heterojunctions, Quantum Wells, and Superlattices. If we have a desirable laser semiconductor material A, and a lattice-matched semiconductor B, with a higher energy gap than A, we can grow a layer of A sandwiched between two layers of B. This double heterostructure (DH) turns out to be very good for laser action because the charge carriers are quickly channeled into A and the index of refraction discontinuity confines the light better to the active region. The first successful room temperature operation was achieved with these structures. If layer A is made very thin, comparable to the DeBroglie wavelength of the electrons in A, the energy levels at the bottom of the band in A become quantized, and the lowest level is shifted upward in a manner similar to the rest energy of a quantum harmonic oscillator. The structure is then termed a quantum well (QW). Exciton effects may increase the oscillator strength of the recombination radiation very greatly in a quantum well (three to four orders of magnitude!). Quantum wells offer a new design variable for the laser engineer. It is possible to fabricate two quantum wells with a thin enough layer of B in-between that the energy levels between the two wells are coupled, so that we speak of multiple quantum wells (MWQ) as opposed to a single quantum well (SQW). If we have many thin layers of A intercalated between thin layers of B, we have a superlattice (SL). Interaction of energy levels between the A and B layers leads to electronic properties intermediate between the bulk properties of A and B, and we have achieved an "artificial alloy" without having a physical mixture of A and B. All of these principles were used in papers presented at this conference.

Semiconductor Crystal Growth. Preparation of the semiconductor materials used in lasers requires some very sophisticated growth techniques, and research in this field is reported in the Solid State Device and Materials Meeting Series*. Most of the laser devices reported in this conference were fabricated in

*G.B. Wright. "Eighteenth Solid State Devices and Materials Meeting: A showcase for Japanese electronics research," Scientific Bulletin, vol 11, No. 3, Jul-Sep 1986, pp 90-100.

epitaxial layers that were grown on substrates of GaAs, InP, or Si. The substrate crystals are usually grown from a bulk melt, and an important quality index for the substrate is that it must be of high electrical resistivity and have a low concentration of dislocations. Dislocations in the substrate tend to propagate into the devices when succeeding epilayers are grown, although it is possible to inhibit this with "buffer" layers or with superlattice buffer layers. This problem is one which causes many observers to have reservations about the ultimate utility of GaAs devices grown on silicon substrates, even though good device performance has been demonstrated.

To grow the epitaxial layers, one can use liquid phase epitaxy (LPE) or vapor phase epitaxy (VPE). If growing from the gas phase and using metalorganic compounds to transport the reactants, with the reaction driven by pyrolysis at a heated substrate, the method is termed metalorganic chemical vapor deposition (MOCVD). A method of increasing popularity in recent years is to grow epitaxially in a high vacuum chamber by evaporation of the reactants from Knudsen cell type ovens. This method is called molecular beam epitaxy (MBE). MOCVD and MBE currently compete to produce the best superlattices with sharp interfaces and lateral uniformity. A "hot" new method combines growth in a vacuum chamber with substitution of MOCVD gas sources for the Knudsen cells of MBE. Dr. Tsang of AT&T Bell Laboratories discussed this in paper D-1 and has named it chemical beam epitaxy (CBE). From the viewpoint of this conference, the competitive merits of each method are to be measured by the cost effectiveness and reliability with which it is possible to produce superior devices.

HIGHLIGHTS OF THE CONFERENCE

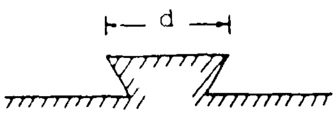
In what follows, I will present a discussion of points that were of personal interest in the conference, while concentrating almost exclusively upon Japanese contributions, because this Bulletin is supposed to reflect research activities in the Far East area. My bias has been toward work that illustrates interesting principles or clever design innovations. Particularly in a conference so devoted to engineering research, it has been more difficult to describe work that makes important advances in practice by incremental improvements. For ease of reference, the titles of the papers are given in the Appendix and will be referred to in very abbreviated form.

Visible and GaAlAs Lasers

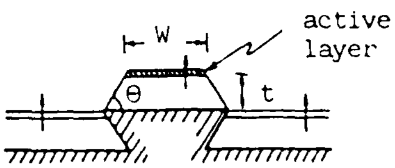
The papers in Session A were concerned with providing efficient new device structures for low threshold operation with good mode stability. Paper A-4, by Yoshikawa et al., is a good example of clever invention to achieve a reliable means of manufacturing a device where small dimensions must be precisely controlled. It also illustrates a very popular laser structure, the buried heterostructure. The goal is to provide an active region with a precisely controlled, narrow width and to encase it with a "cladding" of other material that will confine both the current and the light to the active region. The physics is approximately as follows.

When charge carriers injected into the active region cause an optical gain condition that offsets the cavity losses, the threshold for laser action is achieved. This will occur first for the longest active path length (along the laser axis). There is a certain minimum waveguide width necessary to support

the fundamental transverse optical mode (about one-half wavelength). Any additional width just increases the threshold current and decreases the transverse mode stability. With ordinary photolithography, it is difficult to etch a pattern less than 3 microns wide for the active stripe. Yoshikawa et al. circumvented this problem by taking advantage of the fact that an etchant will attack a GaAs surface anisotropically, depending on the crystal orientation. As shown in Figure 1a, they first etch the substrate to leave a ridge with a flat top of width d. When they grow the new layers on top of the ridge by MOCVD, the growth is also anisotropic, with a fixed angle θ as shown in Figure 1b. To control the width W of the active stripe, they define the ridge width d by photolithography, and the final width W is then controlled by the layer thickness t. But now the photolithographically defined width d is much greater than the active width W, and both it and the thickness t are much easier to control. The entire structure is then buried by subsequent growth and contacted by a diffused zinc contact area. With this geometry the authors fabricated a 3-micron-wide active layer 0.1 micron thick that exhibited a 30-mA threshold current. The completed laser structure, which they termed a ridge buried heterostructure (RBH) laser, is shown in Figure 2. The presentations at the conference were replete with acronyms generated in this fashion. Among the awards given at the banquet was one for the paper with the longest string of acronyms. I reported the paper at some length because to me it typifies the kind of innovation that improves control over manufacturing reliability and moves the devices closer to system applications. Such advances were the spirit of this conference.



(a) Substrate etched to form flat top.



$$W = d - 2t \cot \theta \quad \text{---}(1)$$
$$\theta = 54^\circ$$

(b) New layers grown on top of ridge.

Figure 1. Cross-sectional view of epitaxial layers.

Two papers, A-1 and A-2, reported using AlGaInP ternary alloys lattice-matched to GaAs to achieve short-wavelength visible lasers, while paper A-3 used AlGaAs-GaAs superlattices to achieve the needed higher bandgaps. In paper A-1, Ishikawa et al. achieved room temperature CW operation at 656 nm, with a threshold current density of 1.5 kA/cm^2. Kawata et al. (paper A-2)

investigated the effect on the wavelength and threshold current of changing Al content, and their results are down in Figure 3. Note that this room temperature operation is pulsed. They were able to shorten the wavelength of operation from 680 nm to about 630 nm as Al content increased from zero to 20 percent. The threshold current, however, increased from 3 to 75 kA/cm^2. It will be interesting to see whether this can be improved by growing better quality material or whether there are more fundamental problems associated with the approach of the indirect energy gap of AlAs. The work described thus far used material grown by MOCVD.

Hayakawa et al., in paper A-3, used three different types of quantum wells grown by MBE, whose compositional structure is shown in Figure 4, while the laser structures are shown in Figure 5. As mentioned earlier, single quantum wells (SQW) can be used to obtain a larger energy gap (shorter wavelength of operation) than could be observed in bulk material because of the "rest energy" of the quantum well. The object of paper A-3 was to carry this further and replace the alloy in the single quantum well with a short-period superlattice. The authors succeeded in demonstrating superior performance of the superlattice QW over the alloy QW as shown in Table 1.

Integrated Lasers

Session B dealt with integrated lasers, that is, lasers that are designed with the goal of integrating them monolithically with other elements in future opto-electronic circuits. Requirements for optical communication systems include stable single longitudinal mode operation, with tunability in some cases, and resistance to chirping (wavelength change of the laser under modulation) in others. A number of interesting structures were presented, but I will discuss only one, paper B-3 by Murata et al. Their laser structure is shown in Figure 6. The active gain region is separate from the distributed Bragg reflector (DBR), which selects the frequency of operation. The corrugated feature in the DBR region is a grating whose wavelength selectivity gives rise to the effect called Distributed Bragg Reflection. It is a typical distributed feedback device. If current is injected into the DBR region, the index of refraction is decreased, tuning the DBR, and thus the laser, as shown in Figure 7. The behavior of power output and linewidth is also shown. A laser tuning range of 136 GHz was demonstrated.

Distributed Feedback Lasers

Distributed feedback (DFB) lasers are of particular interest for their use as sources in long-span, high-speed communication lines using fiber cables. It is desired that they operate with a single longitudinal mode (SLM) with high stability, and that the undesired modes (at differing frequencies) have an amplitude at least 30 db less than the main mode. In paper E-4, Yamaguchi et al. showed that advantage can be taken of the difference in light wave intensity distribution along the laser axis between the desired main mode and the undesired competing modes. With the laser structure shown in Figure 8, they provide differential electrical excitation to the two ends of the laser. The success of this strategy is shown in Figure 9, which shows the threshold current and difference in optical gain for the two modes. Not only is the gain differential increased as J_2/J_1 drops below unity, but the threshold current goes down as well.

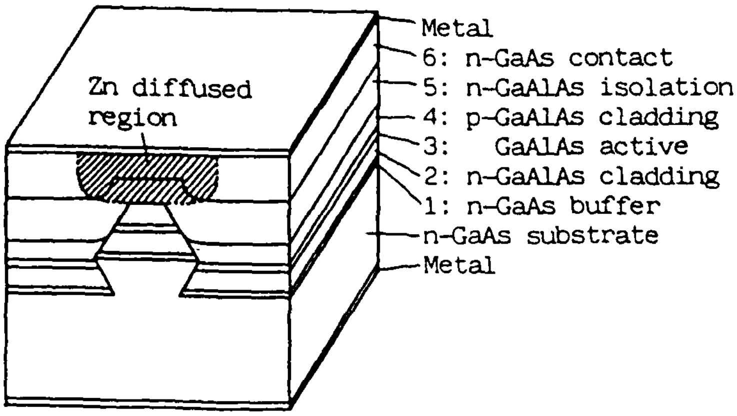


Figure 2. Schematic structure of a ridge-buried heterostructure (RBH) laser.

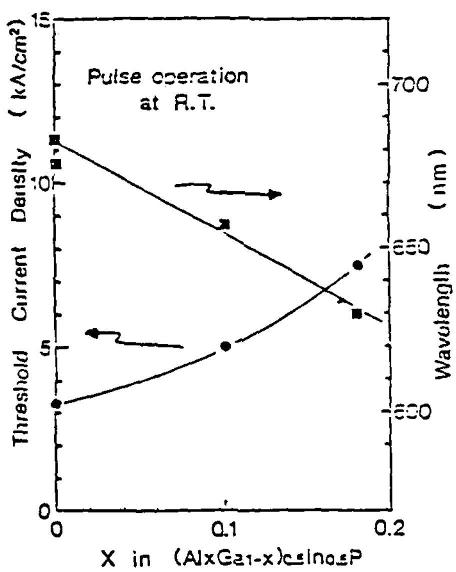


Figure 3. Threshold current density and lasing wavelength as a function of active layer aluminum composition.

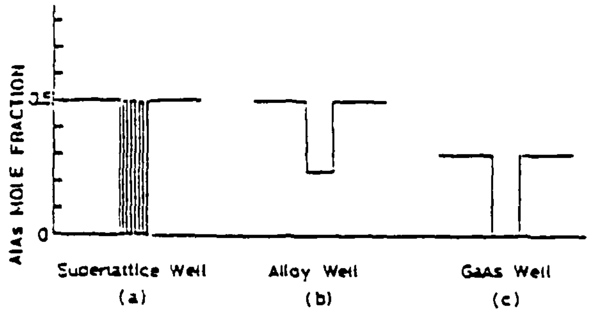


Figure 4. Three types of SQW structures compared in photoluminescence measurements.

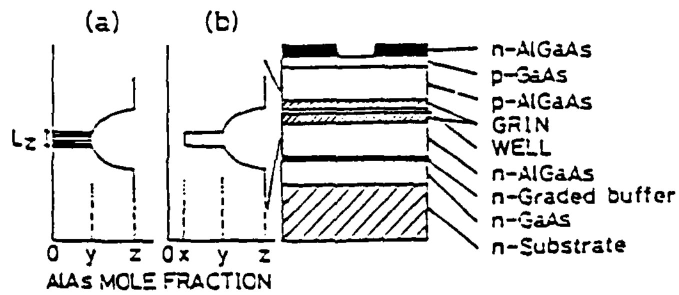


Figure 5. Schematic of HIS type GRIN-SCH lasers with (a) a SL-SQW and (b) an AlGaAs alloy SQW.

Table 1. Comparison of Threshold Current in mA for Alloy QW and Superlattice QW in SQW Lasers

Wavelength (nm)	Superlattice QW	Alloy QW
785	48	71
705	111	116

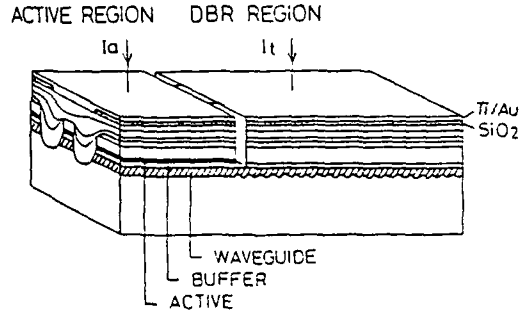
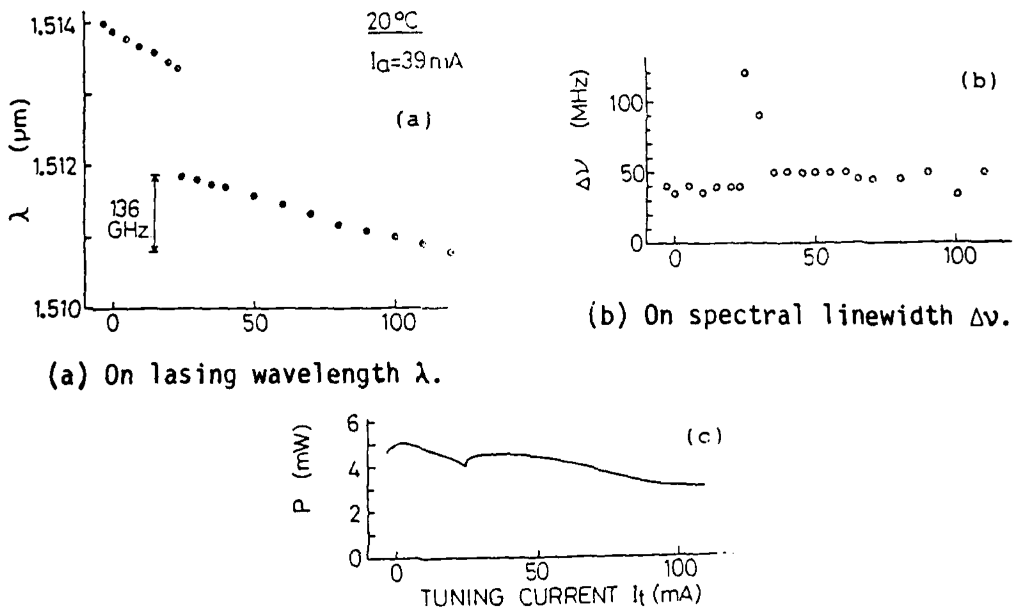


Figure 6. Device structure.



(a) On lasing wavelength λ.

(b) On spectral linewidth Δν.

(c) On light output P.

Figure 7. Tuning current dependence.

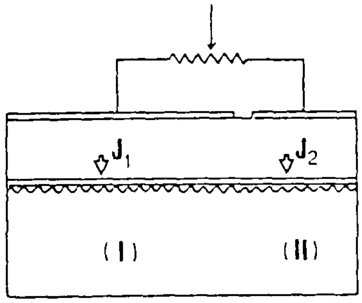


Figure 8. Schematic view of DFB LD with two electrodes.

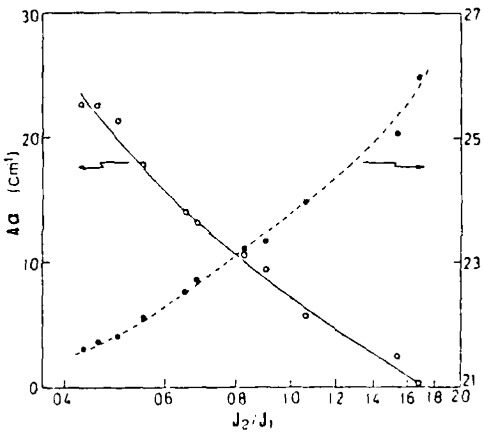


Figure 9. Dependences of Ith and $\Delta\alpha$ on J_2/J_1.

A second paper contributing to improvements in devices for communication systems was E-6 by Okuda et al. They successfully fabricated monolithic arrays of DFB lasers that showed laser action at five wavelengths separated by 5 nm, near 1.3 microns. The lasers all oscillated SLM, with better than 30 dB suppression of the undesired mode, and threshold currents were in the range 20 to 35 mA. In a companion paper (E-7), the crosstalk between lasers in the array was measured. That is, if one laser is operating, how is it affected by operation of a second laser in the array? Not surprisingly, adjacent lasers have the strongest interaction. There can be both thermal and electrical interaction. The maximum wavelength shift of one laser caused by an adjacent one was only 0.25 nm, while a -30-dB electrical crosstalk was measured at a frequency of 1 GHz. The authors concluded that these arrays are already suitable for high-bit-rate, high-density, wavelength-division, multiplexing communication systems.

In paper M-4, Kamite et al. reported achieving bandwidths larger than 9 GHz in a 1.3-micron laser. They achieved this with the structure shown in Figure 10, mesa etched to achieve low parasitic capacitance. The zero-bias capacitance was only 8 pF, and the series resistance was 5 ohms. To get larger differential gain, they detuned 9.5 nm to the short-wavelength side of the gain peak. The resultant resonant frequency as a function of power is shown in Figure 11, and the small signal response is shown in Figure 12. They report that they measured resonant frequencies as high as 15 GHz.

High Power Lasers

Session K on high power lasers was devoted almost entirely to descriptions of processing techniques that various groups had used to obtain promising laser structures. In high power lasers, one is concerned with catastrophic degradation of the laser facets (mirrors). This occurs because the recombination of carriers at the surface may be much more rapid than in the bulk, dumping a large amount

of extra energy into the surface, with resultant temperature runaway and damage. Several schemes to avoid this, essentially by keeping the current away from the surface, were described. For the higher powers, longer cavities, in the range of 300 to 800 microns, were used, and output powers of 100 to 200 mW were obtained. One paper (K-1) was concerned with coupling 1.3-micron light into an optical fiber and reported achieving a coupled power of over 110 mW.

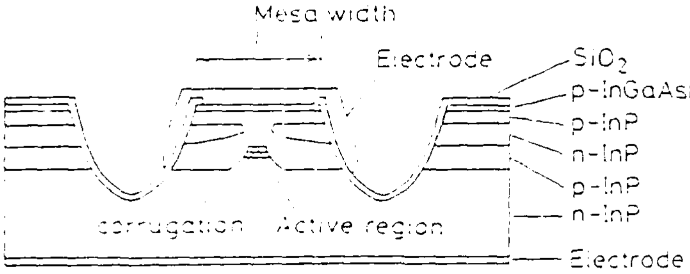


Figure 10. A schematic diagram of FBH DFB laser with mesa structure.

In Session F, Kadowaki et al. (paper F-6) reported high power output from a phase-locked array of five GaAs stripe lasers. The essential idea here is that the parallel stripe lasers interact and become phase locked, so that their output combines coherently. The authors reported output power of 400 mW at room temperature, and furthermore measured a resonant frequency of 2.5 GHz for an output power of 50 mW.

Miscellaneous

In closing, I should like to describe two developments which seemed novel and interesting. In paper O-6, Matsui et al. reported that AlGaAs multiquantum well lasers were fabricated by Si-induced disordering of the superlattices. The process is illustrated in Figure 13. It depends on the discovery that if GaAs superlattices are implanted with silicon, and the implantation damage is subsequently annealed, the superlattice dissolves into a (crystalline) alloy, while Be implantation into Si-doped superlattices **preserves** the superlattice in the implanted region, while it dissolves in the nonimplanted regions. The significance is that the superlattice and alloy have differing bandgaps and indices of refraction, so that by patterning the implant, the device geometry is defined. Patterning is achieved by focussed ion beam implantation. This work represents a clever practical utilization of a novel physical effect.

Finally, I should like to describe work reported by W.T. Tsang and R.A. Logan on erbium-doped injection lasers. The physical proposal is shown in Figure 14. The idea is that the erbium ion has a transition in the same energy range as GaInAsP (1.55 microns). If the upper erbium state lines up with the conduction band, perhaps electrical pumping of the Er ion could be achieved, with laser action taking place at the erbium wavelength. They actually carried out experiments that showed a sharp laser line at 1532.2 nm and a low temperature coefficient. However, I think this result is very mysterious. The

erbium transition is a many-electron transition internal to the atom. The valence electrons of the Er impurity will determine where the energy levels line up. Alloying or pressure measurements on the host material should quickly reveal more about this system. With all these reservations, it still was very interesting!

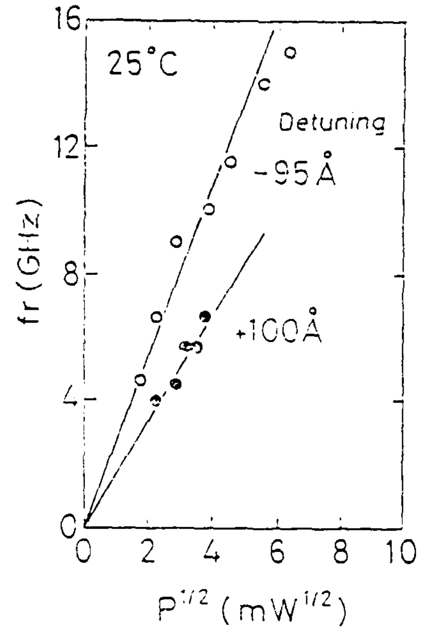


Figure 11. Relaxation oscillation frequency fr vs square root of power from AR facet. Plot by open circle is the case of detuning of 95 Å to the shorter wavelength side of a gain peak, and plot by a closed circle is that of 100 Å to the longer wavelength side.

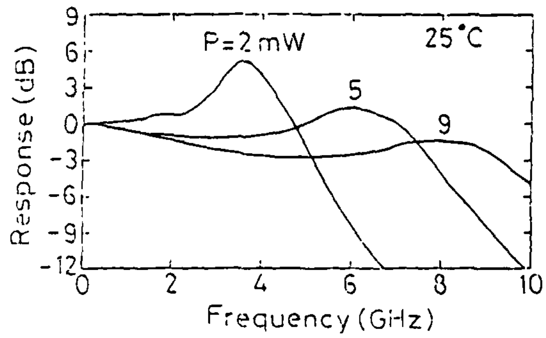


Figure 12. Small signal response of the mesa-FBH-DFB laser of detuning of 95 Å to the shorter wavelength side.

ACKNOWLEDGMENTS

I should like to thank the many people who talked to me, who are in no way responsible for any shortcomings in this report. They include, but are not limited to: J. Coleman, D. Dapkus, I. Hayashi, I. Kaminow, R. Linke, A. Mooradian, Y. Suematsu, I. Suemune, W. Tsang, J. Walpole, A. Yariv, and H. Yonezu.

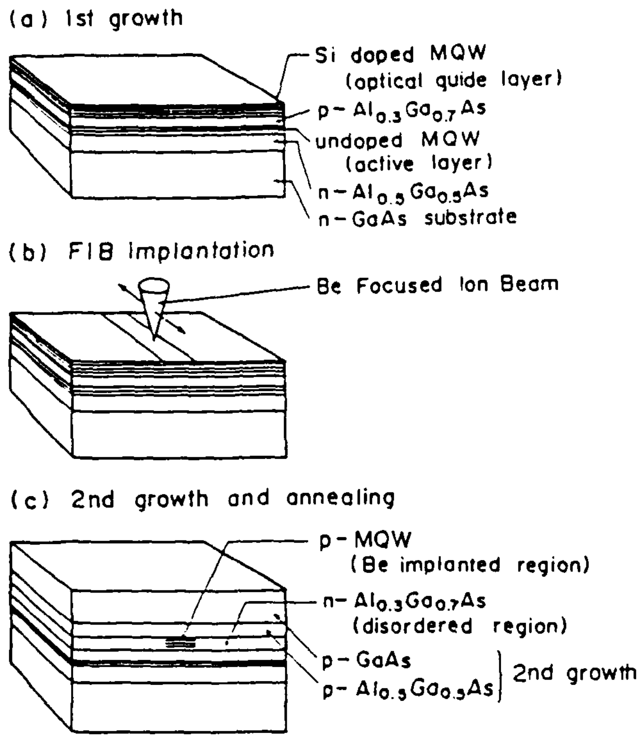


Figure 13. Fabrication processes of MQW-BOG lasers by Be implantation.

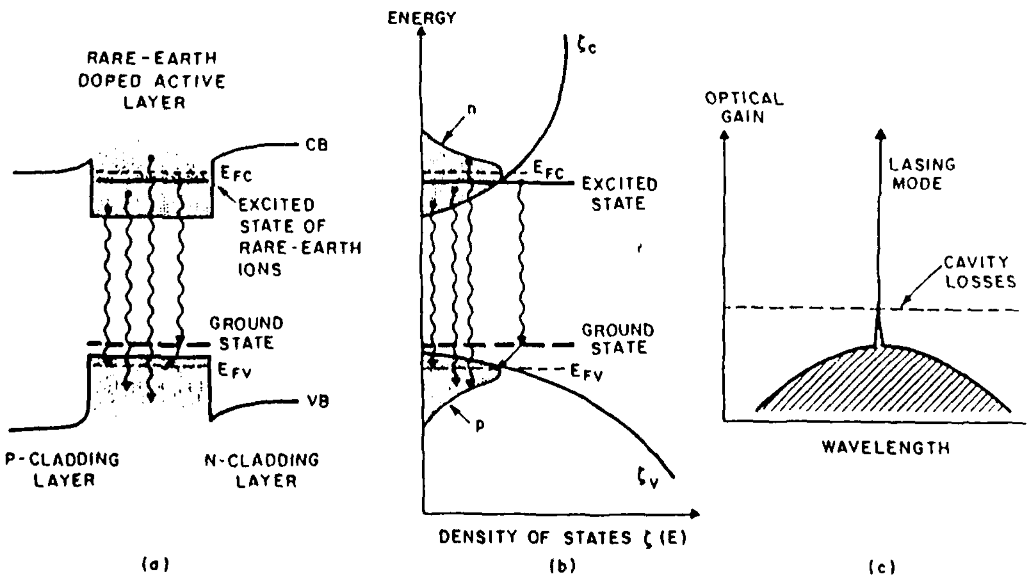


Figure 14. Physical proposal for erbium-doped injection lasers.

APPENDIX

LIST OF CONFERENCE PAPERS

Session A: Visible and GaAlAs Lasers

A–1
Low Threshold Current InGaP/InAlP Transverse Mode Stabilized Lasers
M. Ishikawa, Y. Ohba, H. Nagasaka, Y. Watanabe, H. Sugawara, M. Yamamoto, and G. Hatakoshi, Toshiba, Kawasaki, JAPAN

A–2
Low Threshold AlGaInP Visible Lasers with Aluminum Containing Quaternary Active Layer
S. Kawata, K. Kobayashi, A. Gomyo, I. Hino, and T. Suzuki, NEC, Kawasaki, JAPAN

A–3
Low-Current-Threshold AlGaAs Visible Laser Diodes with an $(AlGaAs)_m(GaAs)_n$ Superlattice Quantum Well
T. Hayakawa, T. Suyama, K. Takahashi, M. Kondo, S. Yamamoto, S. Yano, and T. Hijikata, Sharp, Nara, JAPAN

A–4
A Novel Technology for Formation of Narrow Active Layer in Buried Heterostructure Laser by Single-Step MOCVD
A. Yoshikawa, A. Yamamoto, M. Hirose, T. Sugino, K. Itoh, G. Kano, and I. Teramoto, Matsushita Electronics, Takatsuki, JAPAN

A–5

AlGaAs Self-Aligned Bent Active-Layer Diode with Self-Aligned Window Structure
T. Yagi, K. Yamashita, R. Hattori, M. Kubota, H. Kagawa, M. Ishii, Y. Ohta, T. Tanaka, S. Takamiya, and S. Mitsui, Mitsubishi Elect., Itami, JAPAN

A–6
LPE Grown Infrared (λ=1/3 μm, CW, P=70 mW) and Visible (λ=0.67 μm, CW, P=10 mW) InGaAsP SC DH Lasers with Very Thin Active Region
Zh.I. Alferov, I.N. Arsent'ev, L.S. Vavilova, D.Z. Garbuzov, A.V. Ovchinnikov, and I. S. Tarasov, A.F. Ioffe Physico-Tech. Inst., Leningrad, U.S.S.R.

Session B: Integrated Lasers

B–1
Fabrication and Characteristics of 1.5 μm BH-BIG-DBR Laser Diodes
S. Suzaki, T. Watanabe, T. Nomura, H. Katsuda, and H. Osanai, Fujikura, Tokyo, JAPAN

B-2
Spectral Behaviour of 1.5 μm Bundle-Integrated-Guide Dynamic Single Mode (BIG-DSM) Lasers
L. Posadas, K. Komori, Y. Tohmori, S. Arai, and Y. Suematsu, Tokyo Inst. of Tech., Tokyo, JAPAN

B-3
Spectral Characteristics of 1.5 μm DBR DC-PBH Laser with Frequency Tuning Region
S. Murata, I. Mito, and K. Kobayashi, NEC, Kawasaki, JAPAN

B-4
Monolithic Integration of DFB Lasers and MQW Optical Modulators
Y. Kawamura, K. Wakita, Y. Yoshikuni, Y. Itaya, and H. Asahi, NTT, Atsugi, JAPAN

B-5
AlGaAs/GaAs GRIN-SCH SQW Lasers Applied to Optoelectronic Integrated Transmitters
O. Wada, T. Sanada, H. Nobuhara, M. Kuno, M. Makiuchi, and T. Fujii, Fujitsu Labs., Atsugi, JAPAN

B-6
Monolithically Integrated Hybrid AlGaAs Heterostructure Laser with DBR on Sputtered Dielectric Waveguide
Zh.I. Alferov, S.A. Gurevich, E.L. Portnoi, and F.N. Timofeev, A.F. Ioffe Physico-Tech. Inst., Leningrad, U.S.S.R.

Session C: Linewidth and Chirping

C-1
Spectral Linewidth of AlGaAs/GaAs Distributed Feedback Lasers
K. Kojima, S. Noda, S. Tai, K. Kyuma, K. Hamanaka, and T. Nakayama, Mitsubishi Elec., Amagasaki, JAPAN

C-2
The Relationship of Line Narrowing and Chirp Reduction Resulting from the Coupling of a Semiconductor Laser to a Passive Resonator
C. H. Henry and R. F. Kazarinov, AT&T Bell Labs., Murray Hill, U.S.A.

C-3
The Linewidth of a Modelocked Semiconductor Laser Caused by Spontaneous Emission: Experimental Comparison with Single Mode Operation
D.W. Rush, P.-T. Ho, and G.L. Burdge*, Univ. of Maryland and *Lab. for Physical Sci., College Park, U.S.A.

C-4
Experimental Measurement and Theoretical Evaluation of the Chirping to Power Ratio in Injection-Locked Semiconductor Lasers
P. Sano, S. Piazzolla, and M. Tamburrini, Fondazione U. Bordoni-ISPT, Roma, ITALY

C-5
Linewidths and Nonlinear Gain Enhanced FM Response of BH and DFB Lasers
W. H. Nelson, P. Melman, and E. Eichen, GTE Labs., Waltham, U.S.A.

C-6
Linewidth Broadening Factor in Semiconductor Lasers
M. Osinski and J. Buus*, Univ. of New Mexico, Albuquerque, U.S.A. and *Plessey (Caswell), Towcester, U.K.

Session D: Material

D-1
Chemical Beam Epitaxial Growth of Very Low Threshold $Ga_{0.47}In_{0.53}As/InP$ Double-Heterostructure and Multiquantum Well Lasers
W. T. Tsang, AT&T Bell Labs., Holmdel, U.S.A.

D-2
Low-Threshold Optically Pumped Lasers Grown by Metalorganic Chemical Vapor Deposition on Ge/Si Substrates
R. D. Dupuis, J. P. van der Ziel, and J. C. Bean, AT&T Bell Labs., Murray Hill, U.S.A.

D-3
AlGaAs/GaAs Stripe Laser Diodes Fabricated on Si Substrates by MOCVD
S. Sakai, X. W. Hu, T. Soga*, and M. Umeno, Nagoya Inst. of Tech. and *Nagoya Univ., Nagoya, JAPAN

D-4
Planner Surface Buried Heterostructure InGaAsP/InP Lasers with Hydride VPE Grown Fe-Doped Highly Resistive Current Blocking Layers
S. Sugou, Y. Kato, and K. Kasahara, NEC, Kawasaki, JAPAN

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M. Razeghi, M. Krakowski, R. Blondeau, K. Kazmierski, P. Hirtz, J. Ricciardi, B. de Cremoux, and J. P. Duchemin, Thomson-CSF, Orsay, FRANCE

D-6
16 μm CW PbSnSe Tunable Lasers and Their Applications in High-Resolution Spectroscopy
H. Wang, X. Zhu, W. Zhang, G. Cao, H. Chen, and H. Yang, Shanghai Inst. of Optics and Fine Mechanics, Shanghai, CHINA

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S. Tsuji, A. Ohishi, M. Okai, M. Hirao, and H. Matsumura, Hitachi, Kokubunji, JAPAN

E–2
Stability in Single Longitudinal Mode Operation in GaInAsP/InP Phase Adjusted DFB LD's
H. Soda, Y. Kotaki, H. Sudo, H. Ishikawa, S. Yamakoshi, and H. Imai, Fujitsu Labs., Atsugi, JAPAN

E–3
Asymmetric λ/4–Shifted InGaAsP/InP DFB Lasers
M. Usami, S. Akiba, and K. Utaka, KDD, Tokyo, JAPAN

E–4
Improvement of Single Longitudinal Mode Stability by Gain Profile Control in DFB LD
M. Yamaguchi, Y. Koizumi, I. Mito, and K. Kobayashi, NEC, Kawasaki, JAPAN

E–5
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R. G. Plumb, G. D. Henshall, A. J. Collar, and C. J. Armistead, STL, Harlow, U.K.

E–6
5–Wavelength Integrated DFB Laser Arrays with Quarter–Wave–Shifted Structures
H. Okuda, Y. Hirayama, H. Furuyama, J. Kinoshita, and M. Nakamura, Toshiba, Kawasaki, JAPAN

E–7
The Crosstalk Characteristics of Integrated 5–Wavelength DFB Laser Arrays
H. Furuyama, H. Okuda, Y. Hirayama, M. Ito, T. Atsumi, M. Morinaga, and M. Nakamura, Toshiba, Kawasaki, JAPAN

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Monolithic Integration of a Laser and a Lens for Beam Convergence
S. Mukai, M. Watanabe, H. Itoh, and H. Yajima, ETL, Tsukuba, JAPAN

F–2
A Very Narrow Beam AlGaAs Laser with a Thin Tapered–Thickness Active Layer
T. Murakami, K. Ohtaki, H. Matsubara, T. Yamawaki, H. Saito, A. Shima, H. Kumabe, and W. Susaki, Mitsubishi Elec., Itami, JAPAN

F–3
New Design for Efficient, Stable–Supermode Phased–Array Lasers
W. Streifer, M. Osinski, D.R. Scifres*, D.F. Welch*, and P.S. Cross*, Univ. of New Mexico, Albuquerque and *Spectra Diode Labs., San Jose, U.S.A.

F–4
External Cavity Phase Locking of an Index Guided Laser Array
J.P. Bouzinac*, D.F. Welch, P. Cross, D. Scifres, W. Striefer*, and R.D. Burnham**, Spectra Diode Labs., San Jose, *Univ. of New Mexico, Albuquerque and **Xerox, Palo Alto, U.S.A.

F-5
Injection Locking Characteristics of 10, 20 and 40 Element Coupled Stripe Arrays
L. Goldberg and J. F. Weller, Naval Res. Lab., U.S.A.

F-6
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T. Kadowaki, T. Aoyagi, S. Hinata, N. Kaneno, Y. Seiwa, K. Ikeda, and W. Susaki, Mitsubishi Elec., Itami, JAPAN

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Extremely Low Threshold Current 1.53 μm InGaAsP/InP MS-DFB Lasers with Second Order Grating
H. Burkhard, E. Kuphal, and H. W. Dinges, Forschungsinst. der Deutschen Bundespost, Darmstadt, F.R. GERMANY

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Short Cavity GaInAsP/InP DFB Lasers with High Reflectivity Mirror
Y. Itaya, H. Saito, and G. Motosugi, NTT, Atsugi, JAPAN

G-3
Resonance Frequency in DFB Lasers
S. Tsuji, T. Ohtoshi, M. Hirao, and H. Matsumura, Hitachi, Kokubunji, JAPAN

G-4
Design Optimization of Second-Order DFB Lasers for Dynamic Single-Mode Operation
J. Glinski and T. Makino, BNR, Ottawa, CANADA

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MOVPE-Grown 1.5 μm DFB Lasers on Corrugated InP Substrate
M. Oishi, M. Nakao, Y. Itaya, and Y. Imamura, NTT, Atsugi, JAPAN

G-6
Entirely VPE-Grown 1.5 μm-DFB Lasers with Low Threshold Currents
T. Nishibe, M. Funamizu, H. Okuda, H. Furuyama, Y. Hirayama, M. Nakamura, and M. Iwamoto, Toshiba, Kawasaki, JAPAN

G-7
Low Threshold Current AlGaAs/GaAs Rib-Waveguide-SCH-DFB Lasers Grown by MOCVD
K. Honda, S. Hirata, T. Ohata, S. Horii, and C. Kojima, Sony, Yokohama, JAPAN

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Z. L. Liau, J. N. Walpole, and L. J. Missaggia, MIT, Lexington, U.S.A.

H–2
Low Threshold Circular Buried Heterostructure (CBH) GaAlAs/GaAs Surface Emitting Laser
S. Kinoshita, T. Odagawa, T. Sakaguchi, and K. Iga, Tokyo Inst. of Tech., Yokohama, JAPAN

H–3
Granting-Surface-Emitting Laser with Dynamic Wavelength Stabilization and Far Field Angle of 4.5 milliradians
G.A. Evans, J.M. Hammer, N.W. Carlson, F.R. Elia, E.A. James, and J.B. Kirk, RCA Labs., Princeton, U.S.A.

H–4
Fabrication and Characteristics of Dry-Etched-Cavity GaAs/AlGaAs MQW Laser
T. Yamada, T. Yuasa, M. Uchida*, K. Asakawa, S. Sugata, N. Takado, K. Kamon, M. Shimazu, and M. Ishii, Optoelectron. Joint Res. Lab. and *NEC, Kawasaki, JAPAN

H–5
CW Operation of 1.3 μm InGaAsP/InP BH Lasers with Ion Beam Etched Facets
N. Bouadma, J. F. Hogrel, and J. Charil, CNET, Bagneux, FRANCE

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A New Monolithic Dual GaAlAs Laser Array for Read/Write Optical Disc Applications
M. Kume, M. Hirose, N. Yoshikawa, H. Shimizu, M. Wada, K. Itoh, G. Kano, and I. Teramoto, Matsushita Electronics, Takatsuki, JAPAN

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Linewidth vs. Length Dependence for an External Cavity Laser
R. A. Linke and K. J. Pollock, AT&T Bell Labs., Holmdel, U.S.A.

I–2
1.5 μm DFB Laser Integrated with Tunable External Cavity
S. Sakano, A. Valster, S. Tsuji, H. Nakamura, H. Matsumura, T.P. Lee*, and A.A. Bergh*, Hitachi, Kokubunji, JAPAN and *Bell Comm. Res. Murray Hill, U.S.A.

I–3
Oscillation Frequency Tuning Characteristics of Fiber-Extended-Cavity DFB Lasers
K-Y. Liou, R.T. Ku*, T.M. Shen*, and P.J. Anthony*, AT&T Bell Labs., Holmdel and *Murray Hill, U.S.A.

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Line-Narrowed 1.55 μm VPT-DFB Lasers Using Vertically Self-Aligned Si-SiO_2 ARROW Cavities
T.L. Koch, P.J. Corvini, G.D. Boyd, M.A. Duguay, and W.T. Tsang, AT&T Bell Labs., Holmdel, U.S.A.

I-5
High-Power Extended-Cavity Laser at 1.3 μm with a Single-Mode Fiber Output Port
G. Eisenstein, U. Koren, G. Raybon, L.W. Stulz, R.S. Tucker, B.I. Miller, and A.G. Dentai, AT&T Bell Labs., Holmdel, U.S.A.

I-6
Single Frequency Semiconductor Laser by Self-Induced Distributed Feedback in a Photorefractive Phase-Conjugate External Mirror
K.Y. Lau and M. Cronin-Golomb, Ortel, Alhambra, U.S.A.

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J. Sigg, W. Elsässer, and E. O. Göbel, Max-Planck-Inst., Stuttgart, F.R. GERMANY

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N. Ogasawara and R. Ito, Univ. of Tokyo, Tokyo, JAPAN

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Dynamics of Stimulated Emission Processes in Narrow Stripe Graded-Barrier Single Quantum Well (GB-SQW) Lasers
T.J.S. Mattos, N.B. Patel*, F.C. Prince, and A.S. Nunes Jr., UNICAMP, *TELEBRAS, Campinas, BRAZIL

J-3
Switching Characteristics of InGaAsP/InP Bistable Lasers
H.-F. Liu and T. Kamiya, Univ. of Tokyo, Tokyo, JAPAN

J-4
1.3 μm Laser Amplifier with Integrated Passive Waveguides
M. Oberg and B. Broberg, Inst. of Microwave Tech., Stockholm, SWEDEN

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A New Bistable Optical Device and a New Kind of Optical Logic Gate
B. Sun, X. Huang, and J. Dong, Tsinghua Univ., Beijing, CHINA

J-6
The Transient Response and Optical Amplification in a Bistable Double Hetero Junction (DH) Laser
C.-M. Wang and J.-M. Li, Inst. of Semicond., Beijing, CHINA

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S. Oshiba, H. Horikawa, A. Matoba, M. Kawahara, and Y. Kawai, Oki Elec., Hachioji, JAPAN

K-2
High Power and High Efficiency Operation of 1.2-1.55 μm InGaAsP p-Substrate Buried Crescent Laser Diodes

A. Takemoto, Y. Sakakibara, H. Higuchi, Y. Nakajima, Y. Yamamoto, K. Goto, M. Fujiwara, S. Kakimoto, K. Takahashi, H. Namizaki, and W. Susaki, Mitsubishi Elec., Itami, JAPAN

K-3
High Power Operation of a New Self-Aligned Structure (GaAl)As Laser with Selectively Grown Light Absorbing GaAs Layer

S. Nakatsuka, Y. Ono, and T. Kajimura, Hitachi, Kokubunji, JAPAN

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A Novel High-Power Laser Structure with Current-Blocked Regions near Cavity Ends

T. Shibutani, M. Kume, K. Hamada, H. Shimizu, K. Itoh, G. Kano, and I. Teramoto, Matsushita Electronics, Takatsuki, JAPAN

K-5
AlGaAs/GaAs Mode Stabilized LDs Fabricated by Vapor Phase Etching-MOVPE in situ Process

M. Nido, I. Komazaki, K. Kobayashi, M. Ueno, and T. Kamejima, NEC, Kawasaki, JAPAN

K-6
High External Differential Quantum Efficiency (80%) SCH Lasers Grown by MBE

K. Yagi, H. Yamauchi, and T. Niina, Sanyo Elec., Hirakata, JAPAN

Session L: Miscellaneous

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T. Torikai, Y. Sugimoto, H. Ishihara, K. Makita, K. Taguchi, T. Sekino, and H. Iwasaki, NEC, Kawasaki, JAPAN

L-2
The Dependence of the Conduction Band Discontinuity ΔE_c on the Interface Charge Density σ at n-$In_{0.53}Ga_{0.47}As$/n-InP Heterojunctions

J.M. Vilela, N. Klötzer, H.W. Marten, E. Kühn, H. Eisele, M.H. Pilkuhn, and E. Kuphal*, Univ. Stuttgart, Stuttgart and *Forschungsinst. der Deutschen Bundespost, Darmstadt, F.R. GERMANY

L-3
The 1.3 μm DCPBH Laser: Accurate DC Modelling, Verified by Measurements on Modified DCPBH Devices

P. I. Kuindersma, M. P. J. G. Versleijen, and A. Valster, Philips Res. Labs., Eindhoven, THE NETHERLANDS

L-4
Continuous Electronic Tunability with Constant Amplitude in Three-Terminal Single-Frequency Lasers

S. W. Corzine and L. A. Coldren, Univ. of California, Santa Barbara, U.S.A.

L-5
A Monolithic Vertical Integration of an InGaAsP/InP Laser and a Heterojunction-Bipolar-Transistor
T.R. Chen, K. Utaka, Y.H. Zhuang, Y.Y. Liu, and A. Yariv, California Inst. of Tech., Pasadena, U.S.A.

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J. E. Bowers, AT&T Bell Labs., Holmdel, U.S.A.

M-2
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R. Olshansky, V. Lanzisera, W. Powazinik, and R.B. Lauer, GTE Labs., Waltham, U.S.A.

M-3
PSK Subcarrier Modulation of Semiconductor Lasers at Frequencies of 16 GHz
J.E. Bowers, AT&T Bell Labs., Holmdel, U.S.A.

M-4
DFB Laser with Bandwidth Larger than 9 GHz
K. Kamite, H. Sudo, M. Yano, H. Ishikawa, and H. Imai, Fujitsu Labs., Atsugi, JAPAN

M-5
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D. M. Fye, R. Olshansky, and V. Lansizera, GTE Labs., Waltham, U.S.A.

M-6
Ultra High Relaxation Oscillation Frequency (≈50 GHz) in Modulation Doped Multiquantum Well (MD-MQW) Lasers: Theoretical Analysis
K. Uomi, T. Ohtoshi, and N. Chinone, Hitachi, Kokubunji, JAPAN

M-7
Planar BH InGaAsP/InP Lasers with Semi-Insulating InP Blocking Layers Grown by MOCVD
U. Koren, J.L. Zilko*, B.I. Miller, G. Eisenstein, and P.K. Tien, AT&T Bell Labs., Holmdel and *Murray Hill, U.S.A.

Session N: Instability and Noise

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Model Hopping Noise and Its Reduction in Semiconductor Lasers
M. Yamada, N. Nakaya, and M. Funaki, Kanazawa Univ., Kanazawa, JAPAN

N-2
Longitudinal Mode Competition and Asymmetric Gain Saturation in Semiconductor Lasers
N. Ogasawara and R. Ito, Univ. of Tokyo, Tokyo, JAPAN

N–3
Low Noise Multi-Mode GaAlAs Lasers with Low Astigmatism
T. Kawano, N. Chinone, S. Nakatsuka, and T. Kajimura, Hitachi, Kokubunji, JAPAN

N–4
Coherence Collapse Instability of Semiconductor Lasers
C.H. Henry, H. Temkin, N.A. Olsson, and R.F. Kazarinov, AT&T Bell Labs., Murray Hill, U.S.A.

N–5
Regimes of Feedback Effects in 1.5-μm Distributed-Feedback Lasers
R.W. Tkach and A.R. Chraplyvy, AT&T Bell Labs., Holmdel, U.S.A.

N–6
Spectral Properties near Threshold of Index-Guided AlGaAs Lasers under Optical Feedback
J. Mink and B. H. Verbeek, Philips Res. Labs., Eindhoven, THE NETHERLANDS

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Spontaneous Emission and Gain in GaAs/AlGaAs Quantum Well Lasers
P. Blood and E.D. Fletcher, Philips Res. Labs., Redhill, U.K.

O–2
Enhanced Optical Nonlinearities in Superlattice Structures due to Exciton Localization and Zone Folding
T. Takagahara, M. Kumagai, and E. Hanamura*, NTT, Musashino and *Univ. of Tokyo, Tokyo, JAPAN

O–3
Enhanced T_0-Values in GaSb/AlSb-Multi Quantum Well Heterostructures
H. Schweizer, E. Zielinski, S. Hausser, R. Stuber, M.H. Pilkuhn, H. Krömer*, S. Subbanna*, and G. Griffiths, Univ. Stuttgart, Stuttgart, F.R. GERMANY and *Univ. of California, Santa Barbara, U.S.A.

O–4
Analysis of Carrier Injection into a Quantum Well Laser Active Layer
M. Sugimoto, R. Lang, and H. Iwata, NEC, Kawasaki, JAPAN

O–5
Systematics of Laser-Operation in GaAs/AlGaAs Multi-Quantum-Well Heterostructures
E. Zielinski, H. Schweizer, S. Hausser, R. Stuber, M.H. Pilkuhn, and G. Weimann*, Univ. Stuttgart, Stuttgart, and *Forschungsinst. der Deutschen Bundespost, Darmstadt, F.R. GERMANY

O–6
Index–Guided AlGaAs Multiquantum–Well Lasers Fabricated by Si–Induced Disordering

K. Matsui, T. Takamori, K. Ishida, T. Fukunaga, T. Morita, E. Miyauchi, H. Hashimoto, and H. Nakashima, Optoelectron. Joint Res. Lab., Kawasaki, JAPAN

Session P: InGaAsP and Longer Wavelength Lasers

P–1
CW Operatioon of Low Threshold GaInAsSb/AlGaAsSb DH Lasers

A.K. Srivastava, C. Caneau, J.L. Zyskind, A.G. Dentai, and M.A. Pollack, AT&T Bell Labs., Holmdel, U.S.A.

P–2
InGaSbAs Injection Lasers

A.E. Drakin, P.G. Eliseev, B.N. Sverdlov, A.E. Bochkarev, L.M. Doiginov, and L.V. Druzhiniha, Labedev Phys. Inst., Moscow, U.S.S.R.

P–3
Low Threshold, High T_0 GaInAsP p–DCC Lasers

T. Hasenberg and E. Garmire, Univ. of Southern California, Los Angeles, U.S.A.

P–4
Influence of Waveguide Design on Threshold Current of InGaAsP–InP Metal–Clad Ridge–Waveguide Lasers

M.–C. Amann and B. Stegmüller, Siemens, München, F.R. GERMANY

P–5
Low Threshold 1.51 μm InGaAsP Buried Crescent Injection Lasers with Semi–Insulating Current Confinement Layer

W.H. Cheng, K.D. Buehring, C.P. Chien, J.W. Ure, D. Perrachoine, D. Renner, K.L. Hess*, and S.W. Zehr*, Rockwell Int., Dallas and *Thousand Oaks, U.S.A.

P–6
Measurement of Shunt Current in InGaAsP Buried Heterostructure Lasers

J. LaCourse, T. Chow, and R.Olshansky, GTE Labs., Waltham, U.S.A.

INTERNATIONAL MEETINGS IN THE FAR EAST
1987-1993

Compiled by Yuko Ushino

The Australian Academy of Science, the Japan Convention Bureau, and the Science Council of Japan are the primary sources for this list. Readers are asked to notify us of any upcoming international meetings and exhibitions in the Far East which have not yet been included in this report.

1987

Date	Title, Attendance	Site	For information, contact
February 22-27	The 6th Conference and Exhibition on Exploration Geophysics	Perth, Australia	Dr. F. Fritz C/-BP Minerals, 200 Adelaide Terrace, Perth, WA 6000
February 28-30	Naval Architectural Engineering Conference	Perth, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
March 10-12	Fine Chemical Exposium	Tokyo, Japan	Secretariat: Japan Management Association 3-1-22 Shibakoen, Minato-ku, Tokyo 105
April 8-11	International Symposium on Physics of Magnetic Materials (ISPMM'87) 18-F50-J150*	Sendai, Japan	Department of Applied Physics, Faculty of Engineering, Tohoku University Aoba, Aramaki, Sendai 980
April 14-17	The 25th International Magnetics Conference (INTERMAG'87) 32-F500-J1000	Tokyo, Japan	The Magnetics Society of Japan Kotohira Kaikan Building, 1-2-8 Toranomon, Minato-ku, Tokyo 105
April 15-18	The First Yukawa International Seminar "Mesons and Quarks in Nuclei"	Kyoto, Japan	YKIS '87, Research Institute for Fundamental Physics, Kyoto University Oiwake-cho, Kitashirakawa, Sakyo-ku, Kyoto 606
April 20-22	International Symposium on Magnetism of Intermetallic Compounds 20-F100-J200	Kyoto, Japan	Department of Metal Science and Technology, Faculty of Engineering, Kyoto University Yoshida-Honmachi, Sakyo-ku, Kyoto 606

*Note: Data format was taken from the Japan International Congress Calendar published by the Japan Convention Bureau.
No. of participating countries
F: No. of overseas participants
J: No. of Japanese participants

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Date	Title, Attendance	Site	For information, contact
April 20-22	International Symposium on Magneto-Optics 10-F50-J150	Kyoto, Japan	NHK Science and Technical Research Laboratories 1-10-11 Kinuta, Setagaya-ku, Tokyo 157
April 20-22	Toyohashi International Conference on Ultrasonic Technology	Toyohashi, Japan	Michiko Takamori, MYU Research 2-32-3-303 Sendagi, Bunkyo-ku, Tokyo 113
April 20-24	The 11th Particles and Nuclei International Conference (PANIC'87) 40-F450-J450	Tokyo, Japan	Professor Koji Nakai, National Laboratory for High Energy Physics 1-1 Uehara, Oho-machi, Tsukuba-gun, Ibaraki 305
April (tentative)	Very Large Systems Intergration Conference	Melbourne, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
April 30-May 1	Australian Academy of Science--Annual General Meeting	Canbella, Australia	Secretariat: Australian Academy of Science GPO Box 783, Canberra, ACT 2601
May 11-14	Japan-China Ultrasonic Waves Conference	Nanjing, People's Republic of China	T. Takagi, Institute of Industrial Science, University of Tokyo 7-22-1 Roppongi, Minato-ku, Tokyo 106
May 11-15	Annual Engineering Conference	Darwin, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
May 11-15	The 31st Annual Meeting of the Australian Mathematical Society	Victoria, Australia	Dr. K. L. McAvaney, Division of Computing and Mathematical, Deakin University Victoria, 3217
May 17-21	The 44th General Assembly of International Magnesium Association 15-F100-J100	Tokyo, Japan	Japan Light Metal Association, Nihombashi-Asahikaikan, 2-1-3 Nihombashi, Chuo-ku, Tokyo 103
May 17-22	World Conference on Advanced Materials for Innovations in Energy, Transportation, and Communications	Tokyo, Japan	CHEMRAWN VI Coordinating Office, The Chemical Society of Japan 1-5 Kanga-Surugadai, Chiyoda-ku, Tokyo 101

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Date	Title, Attendance	Site	For information, contact
May 18-21	1987 Symposium on VLSI Technology	Karuizawa, Japan	Secretariat: Business Center for Academic Societies Japan Conference Department 2-40-14 Hongo, Bunkyo-ku, Tokyo 113
May 22-23	1987 Symposium on VLSI Circuits	Karuizawa, Japan	Secretariat: Business Center for Academic Societies Japan Conference Department Yamazaki Building, 4th Floor, 2-40-14 Hongo, Bunkyo-ku, Tokyo 113
May (tentative)	Symposium for Quantitative Aspects of the Nitrogen Cycle	Brisbane, Australia	Dr. R. J. Myers, CSIRO Division of Tropical Crops and Pastures St Lucia, QULD 4067
June 2-5	Transducers '87 20-F200-J600	Tokyo, Japan	Secretariat: Transducer '87 c/o Sansei International Inc., Fukide No. 2 Building, 4-1-21 Toranomon, Minato-ku, Tokyo 105
June 8-12	1987 International Congress on Membranes and Membrane Processes (ICOM'87) 30-F200-J400	Tokyo, Japan	Institute of Industrial Science, University of Tokyo 7-22-1 Roppongi, Minato-ku, Tokyo 106
July 6-10	The Sixth International Conferenceon the Physics of Non-Crystalline Solids F70-J130	Kyoto, Japan	Professor F. Sakka, The Institute for Chemical Research, Kyoto University Gokanosho, Uji-City, Kyoto 611
July 13-18	The 34th International Field Emission Symposium F40-J80	Osaka, Japan	Dr. Shogo Nakamura, The Institute of Scientific and Industrial Research, Osaka University 8-1 Mihongaoka, Ibaraki-shi, Osaka 567
July 20-25	The Second IFSA (Italy, France Spain, America)Congress (2nd IFSA Congress)	Tokyo, Japan	Secretariat: The Second IFSA Congress c/o The Society of Instrument and Control Engineers, 1-35-28-303 Hongo, Bunkyo-ku, Tokyo 113
July 26-31	XXV International Conference on Coordination Chemistry	Nanjing, People's Republic of China	Professor Xiao-Zeng You, Coordination Chemistry Institute Nanjing, Jansu Province

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Date	Title, Attendance	Site	For information, contact
Undecided	The International Conference on Computers In Chemical Research and Education (the ICCCRE)	Shanghai, People's Republic of China	Dr. Yongzheng Hui, Shanghai Institute of Organic Chemistry, Academia Sinica 345 Lingling Lu, Shanghai 200032
August 8-10	Neutron Scattering Symposium 1987	Sydney, Australia	Professor T. M. Sabine, School of Physics and Materials, NSW Institute of Technology P.O. Box 123, Broadway, NSW 2007
August 12-20	The 14th International Congress of Crystallographers	Perth, Australia	Dr. E. N. Maslen, Centre forCrystallography, University of Western Australia WA 6009
August 17-21	1987 Luminescence International Conference	Beijing, People's Republic of China	Professor Xu Xurong, Chinese Society of Luminescence, Xinmin Street 13 Chang-chun, People's Republic of China
August 19-26	The 18th International Conference on Low Temperature Physics	Kyoto, Japan	Professor Shinji Ogawa, The Institute for Solid State Physics, Tokyo University 7-22-1 Roppongi, Minato-ku, Tokyo 106
August 24-27	The 7th International Conference On Quarks-Leptons Physics in Collision 15-F120-J80	Tsukuba, Japan	Organizing Committee: The 7th International Conference on Physics in Collision c/o National Laboratory for High Energy Physics, 1-1 Uehara, Ohomachi, Tsukuba-gun, Ibaraki 305
August 26-29	Pacific Rim Congress 87 International Congress on the Geology Structure, Mineralisation and Economics of the Pacific Rim	Gold Coast, Australia	Mr. E. Brennan, Congress Convenor, The Australasian Institute of Mining Metallurgy, Clunies Ross House, Royal Parade, Parkville, Victoria 3052
August 27-30	The 6th International Conference on Biomagnetism 20-F300-J500	Tokyo, Japan	Secretariat: The 6th International Conference on Biomagnetism c/o INTER Group, Akasaka Yamakatsu Building, 8-5-32 Akasaka, Minato-ku, Tokyo 197

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August 31– September 4	The 8th International Symposium on Plasma Chemistry	Tokyo, Japan	Professor Kazuo Akashi, Metallurgy, Faculty of Engineering, University of Tokyo 7-3-1 Hongo, Bunkyo-ku,Tokyo 113
August (tentative)	The 10th International Congress of Pharmacology	Sydney, Australia	Professor J. Shaw, Secretary, Interium Organising Committee, Department of Pharmacology, University of Sydney NSW 2006
August (tentative)	International Congress for Pharmacology, Satellite on Cardio-Active Drugs	Hayman Island, Australia	Australian Convention and Travel Services GPO Box 1929, Canberra, ACT 2601
September 2-4	Structural Engineering Conference	Melbourne, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
September 6-11	The Sixth Pacific Basin Conference	Beijing, People's Republic of China	Dr. Chih Wang, 3110 Chintimini Drive, Corvallis, Oregon 97330, USA
September 16-18	International Symposium on Optical Memory	Tokyo, Japan	Optoelectronic Industry and Technology Development Association 5th Floor, No. 20 Mori Building, 2-7-4 Nishi-Shimbashi, Minato-ku, Tokyo 105
September (tentative)	Submarine Technology Conference	Canberra, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
October 6-9	IMACS/IFAC International Symposium on Modeling and Simulation of Distributed Parameter Systems	Hiroshima, Japan	Professor Tanehiro Futagami Civil Engineering, Hiroshima Institute of Technology 725 Miyake, Itsukaichi-cho Saeki-ku, Hiroshima 731-51
October 12-16	The 12th International Conference on Atomic Collisions in Solids	Okayama, Japan	Professor Fuminori Fujimoto, Physics Section, College of General Education, University of Tokyo 3-8-1 Komaba, Meguro-ku, Tokyo 153

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Date	Title, Attendance	Site	For information, contact
October 15-16	Microoptics Conference '87	Tokyo, Japan	Professor Kenichi Iga, Program Cochair MOC '87 Tokyo Institute of Technology 4259 Nagatsuta, Midori-ku, Yokohama 227
October 18-24	International Towing Tank Conference (ITTC) 30-F100-J100	Kobe, Japan	Society of Naval Architects of Japan (SNAJ) Sempaku-Shinko Building, 8th Floor, 1-15-16 Toranomon, Minato-ku, Tokyo 105
October 20-23	International Conference on Quality Control--1987 Tokyo 45-F350-J400	Tokyo, Japan	Union of Japanese Scientists and Engineers 5-10-11 Sendagaya, Shibuya-ku, Tokyo 151
November 4-6	'87 International Symposium on Science and Technology of Sintering	Tokyo, Japan	Professor Shigeyuki Somiya Sintering '87, Tokyo c/o Nikkan Kogyo Shimbun, Ltd., Planning Bureau 8-10 Kudan Kita 1-chome, Chiyoda-ku, Tokyo 102
November 9-13	The 2nd International Conference on Refractories 6-F170-J270	Tokyo, Japan	Secretariat: The 2nd International Conference on Refractories c/o International Congress Service, Inc. Kasho Building, 2-14-9 Nihombashi, Chuo-ku, Tokyo 103
November 15-18	1987 Global Telecommunications Conference (GLOBECOM'87) 30-F500-J700	Tokyo, Japan	Secretariat: GLOBECOM'87 c/o KDD Research and Development Laboratories 2-1-23 Nakameguro, Meguro-ku, Tokyo 153

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January 28-31	Royal Australian Chemical Institute, Division of InorganicChemistry, National Meeting (COMO 13)	Melbourne, Australia	Dr. P. Tregloan, Department of Inorganic Chemistry, University of Melbourne Parkville, Victoria 3052
February 2-5	The International Association of the Institute of Navigation (IAIN) Congress	Sydney, Australia	The Australian Institute of Navigation Box 2250, G.P.O. Sydney, New South Wales, Australia 2001

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Date	Title, Attendance	Site	For information, contact
February 22-26	Engineering Conference	Sydney, Australia	The Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
February (tentative)	The 10th Australian Electron Microscopy Conference	(Undecided)	Secretariat: Australian Academy of Science GPO Box 783, Canberra, ACT 2601
April 10-12	The 4th International Conference on Aluminium Weldment 32-F100-J150	Tokyo, Japan	Japan Light Metal Welding and Construction Association (JLWA) Yura Building, 3-37-23 Kanda-Sakumacho, Chiyoda-ku, Tokyo 101
April 26-May 3	The 3rd World Biomaterials Conference 15-F500-J500	Kyoto, Japan	Japan Society for Biomaterials c/o Institute for Medical and Dental Engineering, Tokyo Medical and Dental University 2-3-10 Kanda-Surugadai, Chiyoda-ku, Tokyo 101
May 16-20	The 4th International Conference on Metalorganic Vapor Phase Epitaxy	Hakone, Japan	Professor T. Katoda, Secretary, ICMOVPE IV c/o International Congress Service, Inc. Kasho Building 2F, 2-14-9 Nihombashi Chuo-ku, Tokyo 103
June 5-10	The 6th International Conference on Surface and Colloid Science	Hakone, Japan	Division of Colloid and Surface Chemistry, The Chemical Society of Japan 1-5 Kanda-Surugadai, Chiyoda-ku, Tokyo 101
June 6-10	International Conference on Physical Metallurgy of Thermomechanical Processing of Steels and Other Metals 30-F100-J200	Tokyo, Japan	Nippon Tekko Kyokai 3rd Floor, Keidanren Kaikan, 1-9-4 Otemachi, Chiyoda-ku, Tokyo 100
July 1-12	The 16th International Congress of Photogrammetry and Remote Sensing 65-F1,000-J1,000	Kyoto, Japan	Japan Society of Photogrammetry 601 Daiichi Honan Building, 2-8-17 Minami-Ikebukuro, Toshima-ku, Tokyo 171
July 17-23	International Congress of Endocrinology N.A.-F1,500-J2,000	Kyoto, Japan	Japan Endocrine Society c/o Seirenkaikan Kyoto Furitsu Medical University Nishizume Konjinbashi, Kamigyo-ku, Kyoto 602

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Date	Title, Attendance	Site	For information, contact
July 18-22 105	1988 XVI International Conference on Quantum Electronics 30-F300-J700	Tokyo, Japan	Optoelectronic Industry and Technology Development Association No. 20 Mori Building, 2-74 Nishi-shimbashi, Minato-ku, Tokyo
July 25-30	International Conference on Clustering Aspects in Nuclear and Subnuclear Systems 31-F150-J150	Kyoto, Japan	Dr. K. Tanaka, Faculty of Science, Hokkaido University 5-chome, Kita 10-jo, Kita-ku, Sapporo 060
August 1-5	The 10th Congress of the International Ergonomics Association	Sydney, Australia	Ergonomics Society of Australia and New Zealand, Science Centre 35-43 Clarence Street, Sydney, NSW 2000
August 1-6	IUPAC 32nd International Symposium on Macromolecules 50-F500-J1,300	Kyoto, Japan	The Society of Polymer Science, Japan 5-12-8 Ginza, Chuo-ku, Tokyo 104
August 14-19	The Xth International Congress on Rheology	Sydney, Australia	R. I. Tanner, Department of Mechanical Engineering, University of Sydney NSW 2006
August 15-17	International Federation of Automatic Control Symposium	Melbourne, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
August 15-17	Electrical IFAC Conference	Melbourne, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
August 15-19	The 3rd International Phycological Congress	Melbourne, Australia	Dr. M. N. Clayton, Botany Department, Monash University Clayton, Victoria 3168
August 16-19	The 7th International IUPAC Symposium on Mycotoxins and Phycotoxins 38-F100-J200	Tokyo, Japan	Japan Association of Mycotoxicology, Science University of Tokyo c/o Science University of Tokyo 12 Fungagawara-machi, Ichigaya, Shinjuku-ku, Tokyo 160
August 21-26	International Geographical Congress	Sydney, Australia	Secretariat: Australian Academy of Science GPO Box 783, Canberra, ACT 2601

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Date	Title, Attendance	Site	For information, contact
August 22-26	The 5th Australia-New Zealand Conference on Geomechanics	Sydney, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600
November 19-26	The 13th International Diabetes Federation Congress	Sydney, Australia	Professor J. R. Turtle, Professor of Medicine Department of Endocrinology, University of Sydney NSW 2006

1989

Date	Title Attendance	Site	For information, contact
August 13-18	Solar Energy Congress Tokyo 1989 40-F600-J400	Tokyo,	Japanese Section of International Solar Japan Energy Society 322 San Patio, 3-1-5 Takada-no-baba, Shinjuku-ku, Tokyo 160
October (tentative)	Speciality Electric Conference	Sydney, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600
1989 (tentative)	International Conference on Coordination Chemistry	Brisbane, Australia	Professor M.A. Bennett, Research School of Chemistry, ANU P.O. Box 4, Canberra, ACT 2601

1990

Date	Title, Attendance	Site	For information, contact
July (tentative)	The Xth International Congress of Nephrology 10-F1,000-J4,000	Osaka, Japan	Japanese Society of Nephrology c/o 2nd Department of Internal Medicine, School of Medicine, Tokyo 173
1990 Chemeca (tentative)	1990 Applied Thermodynamics	New Zealand	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600

1991

Date	Title, Attendance	Site	For information, contact
August (tentative)	The 16th International Conference on Medical and Biological Engineering 45-F600-J900	Kyoto, Japan	ME Division, Kawasaki Medical School 577 Matsushima, Kurashiki City Okayama 701-01

1992

1993

Date	Title, Attendance	Site	For information, contact
1993 (tentative)	International Federation of Automatic Control Congress	Sydney, Australia	Conference Manager, The Institution of Engineers, Australia 11 National Circuit, Barton, ACT 2600

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